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The Scientific Basis for Silvicultural and Management Decisions in the National Forest System

THE SCIENTIFIC BASIS

FOR

SILVICULTURAL AND MANAGEMENT DECISIONS

IN THE

NATIONAL FOREST SYSTEM

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Foreword

The 737 million acres (298 million hectares) of forests in the United States are a rich resource that produces timber, minerals, wildlife, forage for domestic animals, and water. These forests also provide the environment for tourism, outdoor recreation, retirement, and a multitude of other uses. Whether the lands are publicly owned, owned by industry, or owned by small private landowners, the forest resource manager is faced with the challenge of increasing the output of goods and services without adversely affecting the quality of the forest environment. When public resources like the national forests are involved, the manager must consider what people want as well as what is biologically possible, technically feasible, and economically realistic when developing cultural prescriptions.

The public and its elected officials in Congress have an abiding interest in the management of our national forests. As evidence of this interest, John R. McGuire, then Chief of the Forest Service, appeared before joint Senate Subcommittees in 1976 to present the agency's Renewable Resource Assessment and Program. A compendium of supporting documents prepared by Forest Service scientists entitled "The Scientific Base for Silviculture and Management Decisions in the National Forests--Selected Papers" was made available to the committees and became part of the record of the hearings.

Management challenges today are even more complex than they were a decade ago. We have learned from past management activities and increased our knowledge of forest culture, protection, and use through research. However, regardless of the objectives of management, trees are involved and forest stands are manipulated utilizing silvicultural principles. Silviculture is the scientific basis upon which all management decisions should be made. The long-term objective of all silvicultural prescriptions is a healthy working forest that provides for society's needs. This often means that not all uses and interests can always be accommodated at the same time nor to the extent that all individuals might like. Usually some compromises have to be made, but the decisions are not biologically irreversible and a continuous flow of goods and services is provided to the American public.

This document updates and expands upon the information provided to Congress in the 1976 compendium of papers. It is a basic primer on the scientific basis for silviculture that should help those interested in the management and uses of the forest to understand the considerations and evaluation processes our professionals go through in developing prescriptions to manage our national forests.

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Contents

An Overview of the Ecological Basis for Silvicultural Systems

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Introduction

Silviculture: what is it, what are the choices, and what are the constraints?

A comprehensive discussion of the "ecological basis for silvicultural systems" is too large a task for a single paper. This overview is therefore intended as a framework for subsequent papers on the silviculture and management of major forest types in the United States, the effects of management practices on nontimber resources, and the influences of silvicultural treatments on the occurrence and damage caused by insects and diseases. This is done by first describing the cutting methods used to harvest, regenerate, and culture forest stands, then discussing the biological, physical, climatic, chemical, and anthropogenic factors that influence trees, and concluding with the biological interactions that affect our choices.

Silvicultural Systems

The Society of American Foresters (Ford-Robertson 1971) defines silviculture as the theory and practice of controlling the establishment, composition, constitution, and growth of forests. Oliver (1986) refers to silviculture as the technical service of converting forest land to stands of particular structures, tree sizes, and species compositions for particular uses. Schmidt (Prouty 1987) expands the definition to all forest resources by stating that, "Silviculture is the science and art of managing forests to meet resource needs. No matter the resource or management objective--be it esthetics, water, timber, wildlife, or recreation--silvicultural practices are the driving force, the means used to achieve the desired end." The silvicultural system can then be viewed as the process by which we grow a forest stand for a specific purpose. This process includes all practices over a rotation--harvest or regeneration cuttings, intermediate cuttings, and other cultural treatments--necessary for replacement and development of the forest stand.

The harvest or regeneration cutting methods discussed in this compendium are: selection (single tree and group), seed tree, shelterwood, and clearcutting (Beaufait and others 1983). These cutting methods are also characterized as even aged--trees of approximately the same age and size--or uneven aged--trees of several sizes and ages. Brief descriptions of these even-aged and uneven-aged silvicultural and management options follow; more details on the biological feasibility of applying these methods to our forests are presented in "Silvicultural Systems for the Major Forest Types in the United States" (Burns 1983).

Silvicultural systems in which reproduction cuttings result in an uneven-aged stand include the single tree selection and group selection methods. In these methods, individual trees or groups of mature and immature trees are cut to maintain a desired range of tree sizes or diameter distribution, to regulate the number of trees per unit area and species composition of the stand, and to provide openings for reproduction to become established and grow. Regeneration and intermediate cuttings are activities that continue throughout the life of the stand. Regeneration often becomes established and grows in the openings resulting from the removal of larger trees or groups

of trees. However, openings created by thinnings are usually too small for regeneration of all but the most shade-tolerant species. In practice, regeneration cuts generally occur at intervals or cutting cycles of 15 or more years depending on the productive capacity of the site, the silvics or characteristics of species present, economic considerations, and management objectives.

In the **single tree selection** method, the evaluation of each tree is based on its silvicultural condition--age, merchantability, health, seed production capability, and potential to increase in volume and quality. The selection and removal of single trees creates relatively small openings in the stand similar to those resulting from natural mortality. This condition favors reproduction of the species that can grow in the shade (shade tolerant) over those that require direct sunlight (shade intolerant) for survival and satisfactory growth (Hook and others 1983). Therefore, the single tree method is not appropriate for regenerating shade-intolerant species.

In the **group or modified selection** method, small openings are created in the stand for new regeneration by removing groups of trees. The resulting openings are generally less than one-quarter of an acre in size, but can be as large as 2 acres, especially in the West. These openings permit more direct sunlight to reach the forest floor than with single tree selection, resulting in the regeneration of more shade-intolerant species. The size, shape, and placement of openings can be varied to meet the light requirements of the species being regenerated. Also, opening size is determined by the silvical characteristics of the trees, their size, and the ease in which they can be removed without damaging other vegetation.

Even-aged silviculture refers to harvesting methods that produce stands of trees that are of approximately the same age. Arbitrarily, a stand is considered to be even aged if the range of tree ages is less than 20 years or does not exceed 20 percent of the rotation length. The three major even-aged cutting methods are shelterwood, seed tree, and clearcutting. The methods differ according to the number of cuttings required to remove the mature stand. Cutting under the shelterwood system provides for the establishment and protection of new seedlings before the old stand is entirely removed. Clearcutting is the removal of all trees at the same time. The seed tree method may be considered a variant of clearcutting since the old stand is removed except for the few trees that are left per acre as a source of seed for natural regeneration. These "seed trees" may or may not be removed once regeneration is established.

The essence of the **shelterwood** system is that the next stand of trees is established through natural and/or artificial regeneration before the old one is completely removed. In a series of cuts trees are removed, leaving the more desirable species and healthier trees to provide seed, protect the young seedlings, and increase in volume for the final cut. The shelterwood process may involve a series of three operations: (1) preparatory cuttings designed to stimulate seed production and prepare the seedbed; (2) seed cuttings to establish the new crop of trees; and (3) removal cutting to release the established seedling and harvest the overstory trees. This system provides an almost continuous tree cover, making it desirable from the multiresource protection and use standpoint. In practice, the three cuts are not always needed, and in fact, most shelterwoods in the United States consist of just the seed production and removal cuts.

Clearcutting is the harvesting in one operation of all trees with the expectation that a new, even-aged stand will be established either from advanced reproduction or through natural seeding, stump sprouting, direct seeding, or planting of seedlings. In practice, however, often only the merchantable trees are removed, leaving undesirable species and/or poor-quality stems. It is best to remove these residual trees to provide the conditions required for the growth of advanced reproduction, establishment of new seedlings, and development of sprouts of desirable species. Clearcutting is esthetically the least desirable of the harvest methods. However, the undesirable appearance of the harvested area is temporary and can be improved through careful location of boundaries to fit the landscape, minimizing the acreage to be cut, appropriate cleanup of logging debris, and prompt establishment of reproduction.

In the **seed tree** method, the area is clearcut except for a few seed-producing trees selected to naturally regenerate the harvested area. When feasible, the seed trees are harvested after regeneration is established. In contrast to the shelterwood method, not enough seed trees are left per unit area to significantly shelter or compete with the newly established seedlings. Successful regeneration by this method requires careful selection of the seed

trees, preparation of the seedbed, and control of competing vegetation. In choosing seed trees particular attention should be given to the selection of appropriate species for the site. Also, selected trees must be mature enough to produce abundant fertile seed. This method is not commonly used because of the unreliability of seed crops when they are needed; rapid invasion of competing vegetation; seed tree mortality from insects, diseases, and windthrow; and the inefficiency of harvesting relatively few trees after the area is regenerated.

All cuttings made between the establishment of an even-aged forest stand and the final harvest are termed **intermediate cuttings**, that is, cuttings primarily made to guide or modify development of existing trees, not to establish regeneration. Intermediate cuttings are usually made to remove poorer trees that crowd or in some way limit the growth and development of better trees. Intermediate cuttings are often termed "timber stand improvement" and include thinning, release, improvement, salvage, and sanitation cuts. Timber stand improvement also includes cultural practices such as fertilization and pruning, which are used to increase growth and quality without cutting trees.

Sometimes there are too many trees and a thinning is needed to remove the surplus, thereby reducing competition and increasing the growth and quality of the remaining stems. Thinnings are usually made in immature stands, favor the dominant (taller) trees and better species, and are classified as either commercial--some or all of the wood is utilized--or precommercial--the cut trees are too small to be sold.

Release is a type of intermediate cutting that resembles thinning but is used to regulate species composition or improve the growth and quality of a young stand up to sapling size. Release cuttings often involve removing dominant trees of poor quality or less desirable species that are limiting the development of young growth. Release is also a term used to note the removal or control of competing vegetation other than trees to improve forest stand development and growth.

Improvement cuttings adjust species composition and tree quality in previously unmanaged stands that are older than the sapling stage. Usually, dominant trees of undesirable species, poor form, or unhealthy condition are cut. This cutting would have been termed "release" if carried out when the desirable trees were in the seedling or sapling stage of stand development.

A forester may prescribe a **salvage cutting** to utilize trees that have been killed or damaged by fire, ice storms, or natural catastrophes. If the main purpose of the cutting is to prevent the spread of insects and diseases from infested and infected trees to healthy trees, it is termed as a **sanitation cutting.**

Factors Influencing Trees

The forest stand, in the scheme of biological organization, is analogous to the forest ecosystem, the latter being defined as the complex of living organisms together with their physical and chemical environment (Tansley 1935). The productivity of forest stands, variation in productivity among stands, and stand responses to silvicultural treatments are determined by the biotic (living) and abiotic (inanimate) components of the ecosystem. Thus, an understanding of how environmental factors--biotic and abiotic--influence the establishment, growth, and development of trees is critical to the success of silviculture. A brief discussion of how these factors influence trees follows. More details on the response of the major tree species to environmental conditions can be found in "Silvics of Forest Trees of the United States" (Fowells 1965).

The biotic factors that influence forest trees include associated vegetation, wildlife, domestic livestock, insects, fungi, and countless micro-organisms in the soil. The primary influence of other plants is that they are competitors for light, moisture, and nutrients. The importance of forests to wildlife is well known, with every acre of forest land serving as habitat, that is, providing food and shelter, for one or more species of birds and mammals. Although some regeneration problems are attributed to wildlife depredation of seeds and browsing, the primary concern of the silviculturist is that of enhancing habitat values through integrated management practices. Overgrazing by livestock is known to be detrimental to the establishment of regeneration and the development of young stands, especially hardwood species. However, under proper management, grazing may benefit stand development by reducing shrub, grass, and herbaceous competition.

Of the biotic factors that influence trees, insects and diseases may have the greatest impact upon our silvicultural decisions. For example, as a result of improved fire protection and more intensive management, many of our western forest stands are even aged and overstocked with a limited number of tree species. These conditions can make the forest stand especially vulnerable to insect and disease infestation and infection and require us to address the risk of pest attacks when developing a silvicultural prescription.

Within the limits of biotic influences, the productivity of a forest stand is often dominated by climatic and soil (edaphic) influences. Of these abiotic factors, the quantity and availability of water and nutrients during the growing season are perhaps the most critical. Often, the lack of adequate soil water during the growing season results in reduced tree growth and seedling mortality. Moisture stress resulting from prolonged or frequent drought has also been found to predispose both seedlings and large trees to damage from insects, diseases, and atmospheric pollution. Studies of soil properties that influence storage and moisture availability clearly direct our attention to the importance of this factor in stand management planning. Also, in many parts of the United States, much of the annual precipitation occurs in the winter as snow or as early spring rains when trees are dormant and moisture demand is low. Thus, in addition to total precipitation, an understanding of seasonal distribution of precipitation and the capability of the soil to absorb and store water is critical in making silvicultural decisions.

Decades of sustained forest productivity with minimal external inputs distinguish forest ecosystems from agricultural lands. Much of this productivity comes from the capacity of soils to recycle nutrients in organic materials and the fixation of nitrogen, a critical element for plant growth. These processes are mediated through a myriad of plants, animals, and micro-organisms (biotic influences) and a large number of soil physical and chemical features as well as physiographic and climatic characteristics of the area and land management activities. Silviculture is concerned with the influence of management activities, especially harvesting and site preparation, on the inherent capability of the soil to provide adequate quantities of the nutrients necessary for forest establishment, growth, and development.

By recognizing forest stands as ecosystems and understanding biotic and abiotic influences and interactions, the silviculturist uses a prescriptive approach to develop forest management plans.

Factors Influencing Silvicultural Choice

There is no single silvicultural system that is best for any one geographic region or any forest type. And, no one silvicultural system can produce all the desired combinations of wildlife and fish, water, recreation, tourism, and natural beauty as well as timber from a particular forest, forest stand, or ownership. Thus, the choice of silvicultural system depends on the regeneration and growth requirements (silvics) of the tree species being considered for the area, the interactions of the biotic and abiotic components of the ecosystem to be managed, and the objectives, resources, and expertise of the owner or manager (Society of American Foresters 1981; Stone 1984).

The choice of a silvicultural system to regenerate and manage a particular forest stand or production area involves analysis of social, economic, and managerial considerations. These include size of the stand or forest tract, topography of the land, availability and expertise of personnel, equipment requirements, capital, markets for round wood and fiber, owner objectives, public attitudes, and other resource values. Public attitudes especially with regard to clearcutting have become a factor in the selection of silvicultural systems that can no longer be ignored by the land manager. Public attitudes can also dictate the selection of a cultural method or tool, such as the use of pesticides and prescribed fire, to meet a management objective. Thus, the selection of a silvicultural system is guided by what people think they want as well as by what is biologically possible, technically feasible, and economically realistic.

There are essentially two phases to the process of regenerating a forest stand: first, the removal of existing trees; and second, the establishment of new trees along with the control of competing vegetation. Many possibilities are available for removal varying from the gradual cutting of individual trees, as with single tree selection, to complete removal of all trees or clearcutting of an area. With the exception of adverse weather conditions or fire, removal is entirely within our control, that is, we can cut the trees at our convenience. Once cut however, the establish-

ment of a new forest stand may be difficult, time consuming, and expensive. In the following discussion we will focus on some of the biological and managerial considerations common to the major forest types in the United States.

The silvical characteristics, especially the reproductive habits and requirements, of all trees, both the preferred and the competing species, in the forest stand are among the key factors influencing the choice of a silvicultural system. Chief among these factors is the species' capacity to survive shade and intense root competition for moisture and nutrients. In the successional process of replacement of one species by another, the shade-tolerant species are usually favored and will eventually dominate the forest stand. Nature provides conditions conducive to the regeneration of a forest by means of fire, insects, disease, wind, and other disturbances that remove single trees, groups of trees, a forest stand, or an entire forest. Thus, if we are to simulate nature, the cutting method selected to regenerate a forest stand should provide for the species' specific light requirements. For example, the environment characteristics of even-aged cutting methods favor plant species that require full sunlight for establishment, survival, and good growth.

Silvicultural success requires research-based, site-specific prescriptions. The term "site" is frequently used in forestry with reference to location and also includes the qualitative effects of climate, soil, and biological features of an area on the regeneration and growth of trees. "Site quality" is used by the forester as a quantitative expression of the productive capacity of an area and is usually displayed in terms of tree height relative to its age (site index) or in terms of volume production. It follows, then, that the forester must consider site characteristics, especially those soil factors likely to be growth limiting, as well as shade tolerance when choosing and applying a silvicultural system.

Damage caused by wind, sleet storms, or wet snow can often be prevented by considering the crown and rooting characteristics of the species, the density of the existing forest stand, the physiographic position of the site, and soil- drainage properties when developing the silvicultural prescription. For example, dense forests of shallow-rooted trees on wet, shallow soils in windy exposures are susceptible to windthrow and should be partially cut with extreme care, if at all. Also, because of lower mechanical strength, rapidly growing southern species such as loblolly pine should not be planted too far north where wet snows, sleet, and ice storms will cause excessive breakage. Other climatic hazards to consider include frost heaving of newly established seedlings and sudden exposure of residual trees in partial cuts to extremes of temperature and light, often leading to frost damage, greatly increased transpiration, and abnormal branch or sprout development.

A major consideration in making silvicultural decisions should be the size, age, and vigor of the existing trees; the successional stage of the stand; and an understanding of how trees interact with all other vegetation on the site. Regeneration of an even-aged forest of old trees and declining vigor ordinarily requires a clearcut, seed tree, or shelterwood. Use of selection in these old-growth stands often results in a poor distribution of tree ages and sizes and excessive damage and high mortality among the residual trees. The selection system is better suited to stands that vary in age, size, vigor, and species composition.

The establishment and management of productive forests, particularly of conifer species, often requires that stands be maintained in an early successional or subclimax (seral) condition. This subclimax condition is the most dynamic period, characterized by maximum species diversity and rapid succession. Experience and research have shown that continued uneven-aged management tends to shift the stand toward the climax condition. However, if seral species are desired, then even-aged management is usually necessary to create the environmental conditions required for successful regeneration.

Harvested areas can be either naturally or artificially regenerated, depending upon the existence of an adequate seed supply, the vegetative sprouting capability of the harvested trees (coppicing), weather and seedbed conditions, the cutting method employed, and the characteristics of the site and the species desired. Although natural regeneration is generally cheaper, the lack of seed or unfavorable environmental conditions often delay establishment of a new stand. On the other hand, artificial regeneration--planting and seeding--provides for rapid reforestation of cut-over areas, better control of species composition, and closer regulation of tree spacing than natural regeneration. Planting also offers the opportunity to introduce seedlings that have been genetically improved for superior growth,

quality, and pest resistance into the stand. A discussion of the importance and relationships of genetic improvement to reforestation and other silvicultural practices is provided by Bey and others (1986) in their state-of-the-art article entitled "Tree genetics and improvement."

Whether natural or artificial methods are used, the control of unwanted competing vegetation should be a major consideration in making silvicultural choices. Competition control increases in importance as other intensive and costly cultural techniques such as fertilization, improvement cutting, use of genetically superior planting stock, and genetic selection in natural stands are considered. The methods for controlling unwanted vegetation are numerous and include: mechanical--site preparation ranging in intensity from roller drum chopping to shearing, rootraking, and bedding; chemical--herbicide applications varying from individual stem and spot treatments to aerial spraying of large areas; pyric--prescribed fire; and biological--use of domestic animals, insects, and other plants to consume or eliminate unwanted vegetation. Fire may be used alone or in combination with mechanical and/or herbicidal treatments for competition control and wildlife habitat improvement. Determining which specific treatment or combination of treatments is most appropriate is part of the process of developing a silvicultural prescription.

In the past, prevention and control of fire were considered to be protection matters. Tree resistance to fire damage and the capacity of a site to regenerate following a burn were the only silvicultural considerations. However, prescribed fire is now used to accomplish many management objectives such as: reduce fuel accumulations, control competing vegetation, reduce the spread of diseases, improve wildlife habitat, and prepare sites for regeneration. Periodic prescribed burning is adapted chiefly to even-aged conifer stands because the young regeneration present in uneven-aged stands is easily killed by fire. Also, in uneven-aged stands multiple tree heights make it easier for fire to spread into the crowns of large trees.

Insects and diseases cause substantial damage to our forests, costing landowners millions of dollars annually. While much of this damage and mortality is due to bark beetle infestations and rust infections, the continued spread of gypsy moths into the South and West and increased incidence of root rots are two of many additional areas for concern. The potential for atmospheric pollutants to adversely affect forest tree species also exists. The susceptibility of our forests to pest problems is related to stand and site conditions. Forests that are overmature and very dense or have been subjected to wildfires, excessive grazing, drought, or logging damage are particularly vulnerable. Also, changing ownership patterns and objectives and past management practices such as total fire exclusion and improper cutting methods have resulted in many acres of insect- and disease-prone forests. Weakened trees serve as breeding sites for insects and inoculum sources for diseases that can spread to healthy trees, sometimes killing or damaging all trees on vast areas. Some recent examples, in addition to the spread of gypsy moths from the northeast, are spruce budworms and mountain pine beetles in the West and southern pine beetles and fusiform rust in the South.

Silvicultural treatments can be used to reduce insect and disease risks by selecting appropriate tree species, creating diversity within and among stands in a forest, and maintaining tree vigor. Although good management generally reduces the risk of pest attack or significant damage, there are pest-stand situations that must be considered when choosing and applying a silvicultural system. For example, the risk of damage from dwarf mistletoes, root rots, and bark beetles is significantly increased when stands are managed under the selection system.

Increasing recreational use, wildlife and fish habitat concerns, and a rapidly developing urban interface have resulted in "people pressure" for alternatives to growing timber in making silvicultural choices. Regardless of the output--timber, wildlife, fish, water, or recreation--the choice of silvicultural system to best manage the habitat depends on which species or uses are to be emphasized. For example, even-aged cutting methods required to regenerate trees that are shade intolerant also provide temporary clearings that produce herbaceous and woody vegetation favored by deer, rabbits, and many birds but are regarded as visually unattractive by many people. In contrast, uneven-aged management increases the proportion of shade-tolerant tree species and favors wildlife species that thrive in a mature forest condition, provides streamside and fish habitat protection, and is attractive to the forest visitor or urban dweller. The value of the forest habitat is also influenced by the age, size, form, and health of the trees. Large dead and dying trees or snags

provide habitat for cavity-nesting and insect-eating birds and should be left standing whenever possible. However, some forest visitors consider dead trees to be unsightly and trees dying are often infected with insects or diseases that could spread to healthy trees.

The list of references at the end of this paper and subsequent papers in this compendium should be consulted for more details on the practice of silviculture in the United States. The six-part series sponsored by the Society of American Foresters Silviculture Working Group entitled "Silviculture: The Next 30 Years, the Past 30 Years"; Agriculture Handbook No. 445, "Silvicultural Systems for the Major Forest Types of the United States"; and Agriculture Handbook No. 271, "Silvics of Forest Trees of the United States" are recommended references for all foresters, forest resource managers, and those interested in forest management and uses of the forest.

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Silviculture of Eastern Hardwoods

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Extent and Location of Eastern Hardwood Forests

Deciduous hardwood forests cover some 95.1 million hectares (235 million acres) in the Eastern United States (USDA Forest Service 1973); this represents nearly one-third of the forested area in the entire country. Eastern hardwood acreage on National Forest lands totals about 6.9 million hectares (17 million acres) or nearly 20 percent of the commercial forest land in the National Forest System.

We recognize five major types of eastern hardwood forests (Eyre 1980). The northern hardwood, or beech-birch-maple type, occurs throughout the northern portions of the East and is especially important in the Lake States and New England. The aspen-paper birch type occurs throughout the same region but is especially prevalent in the Lake States. The Allegheny and Appalachian mixed hardwood types occur along the Appalachian Mountains and on the Allegheny and Cumberland Plateaus. These are highly productive mixtures of both northern and southern or central species, with considerable variation from place to place in actual species composition. The oak-hickory and oak-pine types are the most extensive forest types in the United States; they occur throughout the East, but are more prevalent in the Central and Southern States. Bottomland hardwoods occur in the streambottoms of the South and Southeast and include both tupelo-cypress mixtures in the swamps and mixed oak-gum-hardwoods in the intermittently flooded bottoms or stream terraces.

Most eastern hardwood forests originated on abandoned farmland or after heavy cutting or fires during the era of railroad logging in the Eastern United States--about 1880 to 1930. Many stands were commercially clearcut over large areas during this time, and the resulting second-growth is essentially even aged. Furthermore, the distribution of age classes is highly imbalanced--most stands are 50 to 90 years old, and there are relatively few stands in younger or older age classes (Seymour and others 1986).

In addition to the truly even-aged stands, there are considerable acreages of hardwoods that contain several age classes, the result of partial cuttings of one sort or another that provided for regeneration of part of the stand, but did not completely remove the overstory. There is much variation in the degree of stocking and quality of such stands.

Some existing hardwood areas originally supported stands with higher quantities of conifers than at present. Examples are the northern hardwood and Allegheny and Appalachian hardwood areas, where hemlock, white pine, and red spruce and balsam fir stands were once prevalent. Some oak-hickory and oak-pine stands also had larger proportions of loblolly (*Pinus taeda*), shortleaf (*P. echinata*), or pitch (*P. rigida*) pine than they now contain. In many cases, past cutting practices and/or fire have eliminated or reduced these conifer components or even resulted in a change of forest type.

Eastern Hardwoods--A Complex Biological Community

The eastern hardwoods are among the most complex biological communities on earth. There are well over a hundred species of trees that have commercial timber value and many additional species of trees and shrubs of value to wildlife. In the mixed bottomland type alone there are over 70 commercial tree species (Burns and Honkala, in press). Diversity is equally great among the lesser plants and among the animal component of the ecosystem. No other forest types in the United States exceed the hardwoods in the variety of game animals or birds.

Differences among tree species in growth rate, longevity, and value for timber and wildlife add greatly to the complexity of management in stands of eastern hardwoods. Even in stands where all the trees are the same age, it may require as much as 100 years longer for the slow-growing, shade-tolerant species to mature than it does for the fast-growing intolerants (Marquis and others 1984). This often produces stands that are not only a mixture of species, but a mixture of sizes, with the crowns of the various species stratified into horizontal layers (Smith 1972). Such stands are often mistaken for all-aged stands, even though their origin and adaptability to various management techniques is quite different from that of a true all-aged forest.

The different species also have markedly different values. Some are extremely valuable to wildlife--aspen is an outstanding example--as are the mast producers such as the oaks, cherries, and hickories. Characteristics of the wood--its strength, density, fiber length, color, figure (pattern), durability, and workability--determine its value for timber products. Prime examples of the great differences in value that exist are such species as black walnut (*Juglans nigra*), black cherry (*Prunus serotina*), yellow birch (*Betula alleghaniensis*), or red oak (*Quercus rubra*) where veneer-quality logs may bring prices 2 to 10 times higher than comparable logs of other species. And many of the hardwoods are used for speciality products where substitution of another species is not always possible or economically feasible. For example, there is no wood equal to ash for the production of tool handles and baseball bats, to birch for turning, to maple or oak for flooring, or to cherry or walnut for certain styles of furniture.

Ecological Characteristics of Eastern Hardwood Species

Each of the many species of eastern hardwood trees has evolved a unique set of characteristics that adapt it to establishment and growth under particular forest conditions. In terms of natural or ecological succession, the climax species are those adapted to establishment in growing-space vacancies created by relatively minor disturbances, such as the death or removal of a single large tree. Climax species such as American beech (*Fagus grandifolia*) and sugar maple (*Acer saccharum*) are often characterized by production of modest quantities of large seed that is dispersed only short distances, seedlings with the ability to survive and grow under the shade of a forest canopy, slow growth rate, and long lifespan. At the other end of the scale, pioneer species are those adapted to establishment in areas that have been severely or extensively disturbed by such events as lethal fires, extensive windthrow, tree clearcutting, flooding, or agricultural cultivation. Pioneer species such as aspen, cottonwood (*Populus* spp.), and paper birch (*Betula papyrifera*) are often characterized by production of prodigious quantities of small seed that is disseminated over long distances and by seedlings resistant to exposure and adapted to very rapid growth in full sunlight. Between these extremes are many species adapted to establishment in growing-space vacancies of intermediate size or severity.

Climax or shade-tolerant hardwoods include American beech and sugar maple. Pioneer or shade-intolerant hardwoods include both short- and long-lived species. Both groups require severe disturbances to reproduce, but at different intervals. Short-lived pioneer species include the aspens, cottonwoods, and paper birch. Longer-lived, intolerant species are among the most valuable, for they grow rapidly to large size. These include yellow-poplar (*Liriodendron tulipifera*), black cherry, black walnut, white ash (*Fraxinus americana*), red oak, and others. Some intermediate species include the hickories (*Carya* spp.), red maple (*Acer rubrum*), yellow birch, and the white oaks (*Quercus alba*) (Smith 1973, Burns and Honkala, in press). In forest types where truly tolerant species do not occur, intermediates like the hickories, red maple, green ash (*Fraxinus pennsylvanica*), and the white oaks often fill the tolerant's ecological niche. Several bottomland hardwood species associations containing intolerant or intermediate species may

also be perpetuated indefinitely due to depth, duration, and timing of floodwaters.

Forest Cutting Practices for Eastern Hardwoods

Forest cutting practices in eastern hardwoods are based upon the ecological characteristics of the various species (Burns 1983, Society of American Foresters 1981). The objective is to redirect the productive capacity of the forest to optimize some combination of benefits. Since trees naturally tend to occupy all of the available growing space, forest culture almost always involves the removal of some or all of the trees in ways that simulate or accelerate the kinds of natural disturbance that will produce the desired growth or regeneration. Trees removed are usually harvested and their wood converted into timber products, but manipulation of the forest ecosystem for reasons of esthetics, recreation, wildlife, water, or grazing also usually requires the removal of trees. Thus, forest cutting is the primary tool of silviculture, whether or not the timber removed has value for wood products.

Regeneration cutting methods all have the same objective--that of obtaining tree reproduction. And all employ the same technique--that of removing some of the existing vegetation to make available some light, moisture, and nutrients in excess of the needs of the remaining trees so that new trees can get started. The several regeneration methods differ primarily in the degree of cutting or the amount of existing vegetation that is removed; this in turn affects the environmental conditions present for seedling reproduction. Each cutting method is really an attempt to simulate some natural disturbance, to create the environmental conditions conducive to establishment of the particular species desired.

Single tree selection cutting involves the cutting of selected individual trees throughout most or all size classes, creating stands of mixed sizes and ages. It simulates natural disturbances such as might result from the periodic death of scattered trees in a climax forest. Since regeneration is established under the partial shade of the overstory, and new seedlings must survive for long periods of time under this shade, single tree selection cutting is useful as a regeneration cutting method primarily for species that are shade tolerant (USDA Forest Service 1975).

Beech and sugar maple are two commercially important hardwood timber species that are well adapted for regeneration by single tree selection cutting. These two are major components of the northern hardwood forest type and also occur on some sites in the Allegheny and Appalachian mixed hardwood types.

When single tree selection cutting is applied to stands containing intolerant species, the species composition will gradually change as the intolerants are removed and replaced by more tolerant species (Trimble 1965, 1970). Complete stand conversion may require 50 to several hundred years, but stands cut repeatedly by single tree selection will eventually be dominated by a few tolerant species.

Results of single tree selection cutting in forest types that do not contain shade-tolerant species are not entirely predictable. In some cases, intermediate species such as red maple, green ash, white oaks, and hickories increase in predominance and may form a subclimax association, but it is not certain that such associations can be managed to produce high yields over extended periods of time. Such species are often less desirable than the intolerants they replace. In some areas on some sites, particularly in the central types, brush or noncommercial species may be increased rather than trees.

Single tree selection cutting is recommended for regeneration in the northern hardwood type and can be used in selected parts of the Allegheny and Appalachian mixed hardwood types where sugar maple and beech are found, or in the southern bottomland type where desirable intermediate species are present and more tolerant undesirables are absent. In all types, it is recommended only where the objectives do not include perpetuation of high proportions of the intolerant species.

A major advantage of single tree selection cutting is that it leaves the forest with a more natural or undisturbed appearance than any other regeneration cutting method. It is therefore especially suitable in stands where esthetics or recreation values are highest (USDA Forest Service 1980, 1981). Single tree selection is generally less favorable than other cutting methods where increased water yield or wildlife habitat diversity are desired.

The need to cut small as well as large trees has limited the use of selection cutting in many areas

where markets do not exist for small trees. In some cases where selection cutting has been attempted without treatment of the smaller trees, the cuttings have actually amounted to high grading, with subsequent declines in quality and value of the stands. This widespread misuse of the selection system in the 1950's and 1960's contributed to its lack of use today.

Group selection cutting involves the removal of trees in small groups of a few to many trees. Single tree selection is usually practiced in the areas between openings, as well. There is not complete agreement as to the maximum area that should be considered a group, but it is usually less than a fraction of a hectare (an acre), occasionally up to several hectares (acres). Perhaps it would be clearer if the term "group" were used only for openings of less than about 0.2 ha (0.5 acres), and the term "patch" were used for openings of about 0.2-0.8 ha (0.5-2 acres) in which all trees down to a small size are removed (Leak and Filip 1975).

Group or patch selection cuttings simulate moderate disturbance in natural stands and hence are most appropriate for species of intermediate shade tolerance. The method has considerable latitude, however; tolerants also regenerate under group selection and the method can be adapted for some intolerant species by using patch selection with the larger sized openings. Aspen-paper birch in the North and cottonwood and willow (*Salix* spp.) in the South are perhaps the major examples for which some variation of group selection could not be used to perpetuate the type. Most others will reproduce in patch openings, although not necessarily in the proportions or with the efficiency that is possible using other cutting methods. In small patch or group openings, intolerants may reproduce, only to diminish in importance as a result of shading by the border trees. For example, group openings of 0.04-0.24 ha (0.10-0.6 acres) in New England were found to contain only 4 percent intolerants after 15 years, in contrast to 2-hectare (5-acre) clearcuts, which contained 38 percent intolerants (Leak and Wilson 1958).

Just as the ability to reproduce intermediate and intolerant species by group or patch selection varies with size of opening used, so does the effect vary on esthetics and wildlife habitat. Small group openings may create a forest that is very nearly as pleasing to look at as one created through single tree selection cutting and may increase the proportion of some intermediate species; but these small openings provide only minor increases in plant species diversity and in the proportion of intolerant species regenerated. Larger patch cuttings, on the other hand, can provide considerable increases in habitat diversity and in the proportion of intermediate and even intolerant species regenerated. But these patch cuttings are really small clearcuttings, and they may be just as unattractive as larger clearcuttings. Furthermore, even-age regulation of areas by age class becomes much more efficient and effective than uneven-aged regulation as patch size gets larger (Roach 1974). And loss of quality on border trees due to epicormic sprouting can be an important problem with patch cuttings (Smith 1965).

Special circumstances sometimes prevent the use of small openings for regeneration even though the tree species desired may be ecologically suited to them. For example, extremely large deer herds in Allegheny hardwood forests cause severe damage to regeneration, especially in the sheltered areas near the edge of openings. Where the edge represents a major proportion of the opening, as it does in openings less than 1.6-2.0 ha (4-5 acres), deer browsing may completely destroy tree regeneration. Larger openings must generally be used in this situation (Marquis 1981).

Group selection cutting with small groups is especially useful in the northern hardwood type of New England where it provides considerably higher proportions of intermediate species such as yellow birch, very modest improvement in habitat, and almost no loss in esthetics (Leak and Filip 1975). In most other eastern hardwood types, larger group or patch selection openings are required to obtain significant proportions of the less tolerant species. Openings of 0.13-0.40 ha (0.33-1 acre) are commonly recommended (USDA Forest Service 1973, Trimble and McGee 1973). Such cuttings provide good variety in wildlife habitat and are intermediate in their effect on esthetics.

A major objection to group selection cutting is that it can be very complicated to control over a long period of time, even though it may provide the desired regeneration initially (Roach 1974). Difficulties in fitting new openings in among old ones and in regulating timber harvests over a large forest property have prevented its use by many landowners.

Shelterwood cutting involves the complete removal of the existing stand in a series of two or more cuttings,

generally spaced no more than 20 years from start to finish. One or more partial cuttings are made first, retaining some proportion of the overstory to provide seed and shelter for the establishment of new reproduction. Then, the remaining overstory is removed to release the established regeneration which will form a new even-aged stand (USDA Forest Service 1979).

Shelterwood cutting is quite flexible in that the density of sheltering overstory and the amount of time it is retained can be varied to suit the ecological requirements of a wide range of species. It also takes advantage of the fact that ecological requirements of most species vary with stage of development. Most species, including even the shade-intolerant ones, germinate and become established better under partial shade than in the open; but once established, they survive and grow best in full sunlight. Shelterwood cutting provides both sets of conditions--partial shade following the partial cuts, then full sun after final overstory removal.

Shelterwood cutting can be adapted to most hardwood species although it may be less satisfactory than clearcutting for some very intolerants such as aspen. With many other species, its successful use is often determined by local conditions, such as the relative growth rate, shade tolerance, and abundance of competing species. Shelterwood cutting is intermediate in its effect on wildlife habitat, water yield, and esthetics, with the effect dependent upon the density of overstory and length of time it is retained.

Clearcutting, as the name implies, is the removal, in a single cut, of all trees larger than seedlings. However, in some situations, small numbers of trees may be left within the clearcut opening for some special purpose. For example, strips of trees may be left along streams to preserve stream temperatures and avoid any risk of stream sedimentation. Or mast producing trees, or den, nest, or perch trees may be left for wildlife purposes. Or, scattered small stems of certain slow-growing species such as sugar maple and beech may be retained to give them a headstart over faster growing species, thus ensuring representation of the slower growing species in the new stand.

Most of the present eastern hardwood forests are the result of some sort of commercial clearcutting in the past. Hence, most eastern hardwood types can be perpetuated by this method. It is most useful where large proportions of intolerant and intermediate species are desired. It also provides good representation of more tolerant species, although these tend to grow more slowly and be relegated to lower crown positions than the faster growing intolerants.

The success of clearcutting in reproducing many intolerant and intermediate hardwoods is dependent on the presence of these species as advance seedlings prior to cutting. If not present ahead of time, clearcutting will often fail to regenerate such species as the oaks, the maples, ash, black cherry, and American basswood (*Tilia americana*). The widespread success of clearcutting with these species is due to the fact that advance seedlings commonly are present in maturing stands, especially if they have received one or more thinnings in the past. Thus, clearcutting is similar to shelterwood cutting for most of these hardwoods, representing the final removal of the shelterwood sequence in which nature or thinning made the first or seed cut unnecessary. Most regeneration failures with clearcutting in the past have been due to the failure to recognize the need for advance regeneration.

Some species, such as yellow-poplar, the birches, aspen, black willow, and cottonwoods, are exceptions to the above, since these species do not usually occur as advance seedlings. These species may become established after clearcutting if seed is present, seedbeds are suitable, and advance regeneration of other species or herbaceous plants does not interfere.

Clearcutting simulates the most drastic of natural disturbances and permits establishment of plants common to very early ecological successions. When used in a balanced even-age system of management, it creates the widest range of plant communities of any regeneration method; hence wildlife habitat diversity is also greater than under any other regeneration method. Clearcutting also provides the greatest potential for water increase, markedly better than any of the other regeneration methods.

The impact of cutting on the natural appearance of the forest is also greater than with any other cutting method. Most of the criticisms of forest cutting practices that have been voiced in recent years have been aimed specifically at clearcutting, and boil down to displeasure with the appearances of fresh clearcut areas. Attempts to minimize slash and soil disturbance, limits on the size of openings, and their proximity to older ones have helped some, but

clearcuts remain unpleasant sights for many forest users. For this reason, clearcutting is the least suitable cutting method in areas of high recreation use, such as heavily traveled tourist routes and recreation areas (Nyland 1972).

Seed tree cutting is very similar to clearcutting except that a small number of trees are retained as seed sources after clearing. Because most hardwoods reproduce from advance seedlings, from seed stored in the humus, or from sprouts and root suckers, seed tree cutting is seldom used. With the possible exceptions of such light-seeded species as the birches, it produces results identical to clearcutting.

Summary Effects of Various Cutting Methods in Eastern Hardwoods

In the northern hardwood forest type, all of the common regeneration cutting practices can be used to good advantage (Hutchinson 1985, Leak and others 1969, Tubbs 1977). Single tree selection cutting will produce stands dominated by sugar maple and beech and other tolerant species. These species can provide good timber yields under this type of cutting, and the method is recommended for situations where retention of natural appearance is of great importance.

Group selection, using rather small groups, will significantly increase the proportion of yellow birch over single tree selection, and will provide moderate improvement in wildlife habitat with only small loss in natural appearance of the forest. It is recommended over single tree selection cutting for all except the visually most sensitive areas.

Where greater proportions of species such as red maple, white ash, paper birch, and aspen are desired for maximization of timber values or for particular wood products, patch, strip, shelterwood, or clearcutting are all useful, with exact prescriptions depending upon the site and stand conditions, species desired, and importance of other uses. All of these cutting methods, appropriately applied, can also provide benefits to certain species of wildlife and water yield increases.

It is possible to use all of the common regeneration cutting methods in the Allegheny and Appalachian hardwoods, the oak-hickory, oak-pine, and bottomland hardwood types, too, although single tree selection cutting is not as widely appropriate as it is in the northern hardwood type (Marquis and others 1984, Putnam and others 1960, Roach and Gingrich 1968). In stands that contain desirable tolerant or moderately tolerant species, single tree selection cutting will reproduce these species satisfactorily. But in stands where the most tolerant species are less desirable, single tree selection cutting may give unsatisfactory results. In some cases, noncommercial species such as dogwood (*Cornus* spp.), American hornbeam (*Carpinus caroliniana*), eastern hophornbeam (*Ostrya virginiana*), boxelder (*Acer negundo*), striped maple (*Acer pensylvanicum*), or poor quality red maple, oak, or hickories may take over such stands, excluding desired regeneration. This situation can occur in any of those forest types, but is especially common in the oak-hickory and oak-pine types.

In these forest types, methods other than single tree selection are often preferred to favor the less tolerant species. Group or patch selection, with openings of between 0.13 and 0.4 ha (0.33 and 1 acre) in size can be used to secure reproduction of most of the desired species, such as the red oaks, white ash, green ash, black cherry, cucumber tree (*Magnolia acuminata* L.), red maple, and, to some extent, yellow-poplar. Proportions of these valuable species may be less than can be obtained through other methods, but are substantially better than under single tree selection. The pine component is usually reduced in the oak-pine type, all regeneration is severely reduced by deer browsing in the Allegheny hardwood type, and epicormic branching of border trees may cause increased defect in all types after group selection. Many landowners also feel that yield regulation is inefficient and costs of administration high under group selection. As a result, group and patch selection are not usually recommended for these forest types.

Shelterwood and clearcutting methods are well suited to most of these Allegheny and Appalachian, central, and southern mixed types where the most valuable species tend to be intolerant of shade. The choice between the two cutting methods is based primarily on presence of advance regeneration of appropriate size, and wildlife, water, and esthetic objectives for each particular tract. Clearcutting requires fewer entries and is therefore less costly to administer than shelterwood cutting, and is the preferred method except for situations in which shelterwood cutting improves regeneration. When shelterwood cutting is

used, the number, intensity and sequence of cuts, intervals between cuts, and supplementary treatments applied must usually be tailored to the stand conditions and species in which it is used.

Clearcutting is the only cutting method that will produce a large enough water increase to justify cutting for this purpose, but this is likely to be a consideration only on municipal watersheds. Clearcutting also produces more browse and forage for wildlife species such as deer than shelterwood cutting, although shelterwood cutting spreads browse availability out over a longer period of time.

The aspen-paper birch type of the North can be reproduced with assurance only with clearcutting techniques. Although a high proportion of paper birch may regenerate in the northern hardwood type via shelterwood or patch-strip clearcutting (Safford 1983), complete overstory removal is essential to perpetuate the true aspen-paper birch type. Use of lighter cutting will invariably result in conversion of these types to more mixed types, or even to brush under some site conditions. Site preparation and/or control of less desirable species may also be required in some situations.

Because of the tremendous number of tree species that grow in the eastern hardwood forests and their great diversity in ecological requirements, growth rates, and value for timber or wildlife, and because of the great diversity in land-use objectives throughout the Eastern United States, there are no simple prescriptions for managing these forests. There are also wide variations in timber markets, tree values, and operating costs throughout the eastern hardwood region that determine the kinds of silvicultural treatments that are economically feasible. Perhaps more than in any other forest type, there is a need for a wide range of cutting methods and cultural measures, with prescriptions varied to suit each particular tract. Only in this way is the multiple-use potential of these forests going to be fully realized.

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Silviculture of Northeastern Conifers

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Extent and Location of Northeastern Conifer Forests

The northeastern conifer forests are divided into the white-red-jack pine and the eastern spruce-fir type groups. The white-red-jack pine group also includes eastern hemlock (*Tsuga canadensis*), and the eastern spruce-fir group includes the lowland (swamp) conifers northern white-cedar (*Thuja occidentalis*), tamarack (*Larix laricina*), and black spruce (*Picea mariana*). These conifer forests grow on more than 13.4 million ha (33 million acres) in the Northeastern United States, with almost 90 percent of the area classified as commercial timber land (USDA Forest Service 1982). Northeastern conifer forests are concentrated in New England (45 percent) and the Lake States (41 percent), where they grow on 34 percent of the total forest area. Trees in the pine group are generally found on the drier areas and those in the spruce-fir group on the wetter areas, including imperfectly drained and poorly drained soils.

Forest soils in most of the northeastern conifer region developed from glacial deposits (Barrett 1980, Burns 1983). The most productive forest soils are unsorted glacial drift and till material deposited on the midslopes of hills and mountains. The coarser, water-transported, sorted, and stratified drifts found in kames, eskers, outwash plains, and glacial lakes are usually less productive soils. Organic soils that accumulated in filled-lake bogs are often the least productive, but the best bogs may be as productive as good upland sites (Burns and Honkala, in press).

Average annual precipitation ranges from more than 125 cm (50 in) in some places in New England to less than 65 cm (25 in) in some places in the Lake States. Growing season precipitation for April through September, however, is more uniform, with most of the area averaging 45.7-55.9 cm (18-22 in). Average January temperatures range from -1 °C (30 °F) along the east coast to -15 °C (5 °F) in northern Minnesota. Average July temperature is less variable, ranging between 18 and 21 °C (65 and 70 °F)(Kingsley 1985, U.S. Department of Agriculture 1941).

The pines grow commercially on 4.7 million ha (11.5 million acres), with about half the area eastern white pine (*Pinus strobus*)(including white pine-hemlock and hemlock types); 28 percent jack pine (*P. banksiana*); and 22 percent red pine (*P. resinosa*). Most of the white pine and hemlock are in New England, New York, and Pennsylvania. Most of the jack pine and about two-thirds of the red pine are in the Lake States. The spruce-fir forests grow commercially on 7.1 million ha (17.6 million acres), with almost half (47 percent) of the area either balsam fir (*Abies balsamea*), or a mixture of red spruce (*Picea rubens*) and balsam fir. The red spruce type grows on about 7 percent of the spruce-fir area, white spruce (*P. glauca*) on 5 percent, black spruce 13 percent, tamarack 5 percent, and northern white-cedar 28 percent. Most of the red spruce and balsam fir forests (80 percent) are in New England, and most of the white spruce (66 percent), black spruce (80 percent), and tamarack (80 percent) forests are in the Lake States. Northern white-cedar forests are about equally divided between New England and the Lake States.

Northeastern conifers grow on about 0.9 million ha (2.2 million acres) of national forest land in the Region, or about 22 percent of the ownership. In the Lake States, conifers are on 38 percent of national forest land, and in New England on 10 percent. National forests in the Middle Atlantic section (Pennsylvania and West Virginia) have northeastern conifers on 4 percent of their area, and in the Central States on only 1 percent.

Eastern white pine was perhaps the first tree harvested from the northeastern forests. Before the independence of the United States, the tallest and best trees were reserved to provide masts for sailing ships. Most of the early homes, barns, and other buildings were built with white pine lumber. By the middle of the nineteenth century, spruce sawlogs were also being used for lumber (Barrett 1980). About this time the country was expanding rapidly into the rich farm country of the Midwest, and large volumes of lumber were needed to build growing communities. Most of the lumber came from the Lake States pineries in Michigan, Wisconsin, and Minnesota. Farmers in New England abandoned much of the poorer quality land that had been cleared by their ancestors and moved to the Midwest where soils were better suited for agriculture. The abandoned farmland in New England was naturally restocked, much of it with white pine or white spruce.

The old-growth pine forests in the northeastern region were essentially gone by the early 1920's. Extensive areas in the Lake States were burned to clear the land of logging slash expecting that agriculture would follow. Pioneer shrubs and tree species such as aspen (*Populus tremuloides* and *P. grandidentata*) and paper birch (*Betula papyrifera* var. *papyrifera*) became established on much of the former pine lands. Planting programs in the 1930's helped reestablish red pine and jack pine on many acres of open land. After World War II, the availability of herbicides to control broadleaf shrubs and trees allowed planting of conifers such as red pine and white spruce on areas that had converted to shrubs or poor-quality hardwoods following the earlier pine logging. Almost all of today's red pine and white spruce stands in the Lake States were planted.

Following the logging of the old-growth pine and spruce for lumber, the pulp and paper industry dominated use of northeastern conifer wood. In 1976 pulpwood was still 53 percent of the softwood timber production in the Northern region and sawlogs were 42 percent (USDA Forest Service 1982). Other products included posts, poles, piling, cabin logs, and veneer.

Northeastern conifer forests are an important part of the northwoods environment used for recreation, watershed protection, and wildlife habitats, in addition to providing a supply of wood products for stable local economies.

The Pine Type Group

The pine type group includes forest types of predominantly jack pine, red pine, eastern white pine, or eastern hemlock trees. Sometimes two or more tree species grow in mixtures and the type name may include the major ones such as the white pine-hemlock type. White pine is sometimes mixed with hardwood trees that share in the type name like red maple (*Acer rubrum*), northern red oak (*Quercus rubra*), and chestnut oak (*Q. prinus*). Hemlock also grows in mixture with hardwood trees, particularly yellow birch (*Betula alleghaniensis*), to form an important mixed type called hemlock-yellow birch (Eyre 1980). In northeastern Minnesota, a mixed jack pine-black spruce type is recognized. Other trees commonly associated with the pine type group but not sharing in the type name are aspen, paper birch, black cherry (*Prunus serotina*), white ash (*Fraxinus americana*), sugar maple (*Acer saccharum*), white spruce, red spruce, and balsam fir. In addition, basswood (*Tilia americana*), American beech (*Fagus grandifolia*), white oak (*Quercus alba*), sweet birch (*Betula lenta*), gray birch (*B. populifolia*), and northern pin oak (*Quercus ellipsoidalis*) are found in some stands.

The pine type group is native on deep, glacially deposited sands or gravels. Jack pine and red pine predominate on the drier soils, and white pine and hemlock on those with more moisture.

The jack pine forest cover type is native on deep, glacially deposited sands or gravels in the Northeastern United States from Maine to Minnesota. The range of the species is much more extensive to the north and west in Canada (Burns 1983). Jack pine often became the dominant cover type after logging of white and red pine. Scattered jack pine trees mixed with the other pines were often left standing on many cut-over areas and were able to disperse seed after a fire.

Most jack pine trees have cones that hold the seed in tightly closed scales for many years. The large amount of seed held in the crowns of mature trees aids in restocking jack pine after a fire. Fires expose seedbeds, kill the competing shrubs and trees, and the heat opens the cones, releasing their seed. Jack pine trees, especially in the southern part of their range, have nonserotinous cones. Seeds from nonserotinous cones are dispersed soon after ripening in the fall. Good seed crops occur every 3-4 years in mature jack pine.

Jack pine does poorly in any shade. It is often a pioneer tree, seeding in on burns or bare sandy soils, and is usually replaced by more shade-tolerant tree species on all but the dry sandy areas where jack pine may be able to replace itself. Although jack pine is a short-lived tree, a few individuals may live for more than 200 years, and stands of trees sometimes survive up to 100 years. Commercial rotation ages are generally between 40 and 70 years when mature trees are usually 20-30 cm (8-12 in) in diameter and 15-24 m (50-80 ft) tall.

Recommended regeneration methods for mature jack pine stands are clearcutting, seed tree, or shelterwood (Benzie 1977a). Clearcutting is preferred, and is required if the present stand is not a suitable seed source. The genetic quality of many of the present stands is questionable and they should not be regenerated by natural seeding unless no other suitable alternative is available. If the stand is a suitable seed source, and the cones are serotinous, the seed tree method can be used. Site preparation with prescribed fire is recommended to eliminate slash, control shrubs, expose mineral soil seedbeds, and open the cones on the seed trees. The seed trees will be killed by the fire and can be left on the area to improve wildlife habitat. If the stand is a suitable seed source and the cones are nonserotinous, the shelterwood method can be used. Full-tree skidding is recommended to remove the slash. Chemicals to control the shrub and hardwood competition and mechanical equipment to expose mineral soil seedbeds may be needed.

The red pine forest cover type is most common on level to gently rolling sand plains, but is also found on mountain slopes and hilltops. The range of red pine is along the border of the United States and Canada from Maine to Minnesota in a narrow band several hundred km (a few hundred miles) wide. Planted stands now comprise a major portion of the type, and some stands have been established south of the trees' natural range.

Red pine seed crops are irregular, and good crops may be more than a decade apart. Most of the seed is dispersed soon after ripening, about the middle of September, with small amounts released over winter and about 20 percent the following spring (Roe 1964). The thick bark of mature red pine is fire resistant, allowing some trees to survive and provide seed to help restock burned areas.

Red pine can survive in more shade than jack pine, but not as much as white pine. It is a long-lived tree with some stands reaching 200 years, and some individual trees about 400 years. Commercial rotation ages are generally between 60 and 120 years. Red pine often replaces its less shade tolerant and shorter-lived associates such as jack pine, paper birch, and aspen. It may be replaced in turn by its more shade tolerant associates that regenerate more easily in the shade, such as white pine or balsam fir. Red pine has very little genetic variation, showing relatively uniform qualities over the entire range. In some localities, red pine suffers losses from diseases, insects, mammals, and weather, but generally has fewer natural enemies than its associated species.

Red pine forest cover types are generally even aged and depend on planting to establish seedling stands (Burns 1983). Clearcutting is recommended if mature trees are not needed for esthetics. The seed tree and shelterwood harvesting systems have been used in attempts to establish seedlings by natural means, but have not been very successful. Seed tree cutting is no longer recommended, but some form of shelterwood may be useful on esthetically sensitive areas until the seedling stand is large enough to dominate the landscape. Shelterwood trees left in narrow strips about 3.7-4.9 m (12-16 ft) wide and spaced approximately 15 m (50 ft) apart can be harvested in the final removal without damaging the young stand (Benzie 1977b). Managed red pine stands are thinned periodically to control stand composition and provide growing space for the better quality trees. This may favor the growth of shade-tolerant tree seedlings in the understory or the development of dense shrub undergrowth. Controlled summer fires can be used beneath mature red pine trees to kill the competing plants and prepare favorable conditions for establishing red pine

seedlings at the end of the rotation when the mature trees are harvested.

Although red pine is not well suited to uneven-age silvicultural systems, it is sometimes desirable to keep continuous forest cover on special areas. Individual tree selection does not provide large enough openings for red pine seedlings to grow well, hence group selection is preferred.

The white pine forest cover type grows on a wide range of soils--from well-drained sands to silty loams. It is an important type in New England, mid-Atlantic, and Lake State sections of the Northeastern United States. The type also extends north into Canada and south in the Appalachian Mountain range.

White pine trees have good seed crops at 3-10 year intervals (Burns 1983). Although fires create favorable seedbeds, frequent and severe fires can eliminate white pine from forest stands. White pine seed requires about 60 days of stratification before it will germinate. Stratification happens naturally to seed that overwinters on the ground, and it usually germinates 10-15 days after temperatures become favorable in the spring.

White pine is intermediate in shade tolerance. Seedlings can become established and survive in as little as 20 percent of full sunlight. Some shade is beneficial during the establishment period. Once established, optimum growth occurs in full sunlight. The white pine weevil (*Pissodes strobi*) and blister rust (*Cronartium ribicola*) are the most damaging agents of white pine (Burns 1983). The weevil causes most damage in New England and the central part of the white pine range. Blister rust is more severe in the northern and western areas, especially in fog and dew pockets. Some genetic resistance to the rust is being obtained in breeding programs; a limited supply of seedlings with higher-than-average resistance is available.

Mature stands with a well-stocked understory of white pine seedlings can be harvested by clearcutting the overstory trees. If hardwood tree seedlings are competing with the white pine seedlings, some control measures may be necessary to release the white pine. Stands without an understory of well-stocked seedlings should be regenerated by the shelterwood silvicultural system. The first, or seed cut, should remove 40-60 percent of the overstory during or following a good seed year. The soil should not be frozen, so the logging operation will scarify seedbeds.

The removal cut is made after the pine seedling stand is established (Burns 1983). In mixed pine-hardwood stands, the hardwood regeneration may have to be controlled to favor the pine seedlings. On some areas where the white pine weevil is a serious threat, a light overstory of hardwoods may help reduce damage until the white pine trees are tall enough to be out of danger (Lancaster and Leak 1978). Occasionally, planting may be needed to get full stocking of pine seedlings on areas where natural seeding has given poor results.

Other silvicultural systems, including seed tree, clearcutting during or following a good seed crop, and group selection, have been successful, but the shelterwood system is generally preferred because it is more versatile (Burns 1983). The individual tree selection system has usually not been a satisfactory method to establish pine seedlings.

The eastern hemlock forest cover type is most common on moist-to-very-moist soils with good drainage (Burns 1983). Hemlock has a range similar to white pine, but does not extend quite as far west, barely reaching Minnesota.

Hemlock produces good seed crops at 2-3-year intervals, but germination capacity is low, commonly less than 25 percent (Schopmeyer 1974). Dormancy can be broken by stratification or exposure to light. Hemlock seed germinates best at temperatures around 15.6 °C (60 °F)(Godman and Mattson 1985). Favorable seedbeds include moist, well-decomposed litter, rotten wood, mineral soil, and moss mats. The best seedbeds are mixed mineral soils and humus (Tubbs 1978).

Hemlock is very tolerant of shade. Seedlings become established much better under shade than in full sunlight. Seedlings respond well to release and may grow better than seedlings that have never been suppressed (Burns 1983). Hemlock can survive suppression for many years and respond to a gradual release. Although hemlock grows in pure stands, it is more common in mixed stands. It occupies the lower lying areas with moist-to-very-moist soils that have good drainage. Stands can become very dense, accumulating basal areas of 68.9 m^2/ha (300 ft^2/acre) or more (Burns 1983). Old-growth hemlock often suffers wind shake, which causes a separation of

the growth rings. Young trees sometimes suffer from sunscald on the bark when suddenly exposed to direct sunlight. Few insects or diseases cause widespread damage to hemlock. Hemlock is a long-lived tree, reaching 450 years and more of age (Burns and Honkala, in press).

Hemlock seedlings can be established by the individual tree selection system of silviculture because they are very shade tolerant (Burns 1983). In hemlock stands with mixtures of hardwood trees that are also tolerant of shade, some control of the hardwoods may be necessary. Uneven-aged hemlock stands should be managed carefully to protect young trees from overexposure and older trees from wind damage. The group selection system may also be used if openings are kept small, approximately 0.1 ha (0.25 acre).

Even-aged stands of hemlock may be regenerated by the shelterwood silvicultural system. Crown cover of dominant and codominant trees should be at least 50 percent after the seed cut. The removal cut can be made when hemlock seedlings are about 1.5 m (5 ft) tall. In very old stands or on areas where grass, shrubs, and other plants may become dense after cutting, the crown cover should be at least 70 percent after the first cut. A second cut may be used to reduce the crown cover to 50 percent when hemlock seedlings are established, and the removal cut is made when the seedlings are about 1.5 m (5 ft) tall. The soil should be scarified before or during the first cut; hardwoods may need to be controlled during the first and second cuts (Burns 1983).

Seed tree cutting and clearcutting silvicultural systems are not recommended for hemlock stands.

Thinning may be beneficial in dense, even-aged stands. Recommended stand density after thinning ranges from about 23 m^2/ha (100 ft^2/acre) of basal area in the smallest pole stands to 34 m^2/ha (150 ft^2/acre) in the largest sawtimber stands (Burns 1983).

Spruce-Fir Type Group

The spruce-fir type group includes 11 forest cover types recognized by the Society of American Foresters (Eyre 1980). Balsam fir, red spruce, white spruce, or black spruce are key species in all but two of the types. These two types are tamarack and northern white-cedar, which along with black spruce, are most common in lowland (swamp) areas. There are three mixed conifer-hardwood types: paper birch-red spruce-balsam Fir, red spruce-yellow birch, and red spruce-sugar maple-beech. In addition, there are two types with mixed conifer species: red spruce-balsam fir and black spruce-tamarack.

Two subgroups of the spruce-fir type group are upland and lowland forest cover types. The upland types include balsam fir, red spruce, white spruce, and four mixed types with red spruce and one or more of the following species: balsam fir, paper birch, yellow birch, sugar maple, and beech. Other associated tree species in upland spruce-fir types include hemlock, white pine, red maple, aspen, white ash, and basswood. The lowland types include tamarack, black spruce, northern white-cedar, and a mixed type of black spruce-tamarack. Associated species in lowland spruce-fir types include balsam fir, red spruce, white spruce, black ash (*Fraxinus nigra*), red maple, paper birch, aspen, and balsam poplar (*Populus balsamifera*). On better drained sites, hemlock, white pine, and yellow birch trees are sometimes mixed with the lowland spruce-fir type.

Spruce-fir forests dominate many of the less productive areas such as steep mountain slopes in New England and New York, giving way to hardwood forests on the more productive and deeper soils of the lower slopes. The spruce-fir types are most abundant on flats having acid mineral soils with a thick humus layer, and on peat soils commonly found in regions with relatively high rainfall and low evapotranspiration (Barrett 1980, Burns 1983, Frank and Bjorkbom 1973). Some of these acid soils have a pH as low as 4.0. Shallow till soils with an average rooting depth of 46 cm (18 in) or less are common where spruce-fir grows.

Upland Spruce-Fir Subgroup

On the most productive upland sites, northeastern conifer types are transitional and will be succeeded by hardwood types (Barrett 1980). Only red spruce, white pine, and hemlock trees can maintain a position within the hardwood types because of longevity and/or shade tolerance. On areas such as flats and lower slopes where soil drainage is somewhat impeded, the spruce-fir type can successfully compete with hardwood trees. Because spruce and balsam fir

seedlings can grow in shade, the spruce-fir type can often maintain itself on these areas (Burns 1983).

Balsam fir is a small-to-medium-size tree, and relatively short lived. Average tree diameter in mature stands may reach 30-46 cm (12-18 in) and average heights from 12.2-18.3 m (40-60 ft), depending on site quality. Although individual trees have been reported to live up to 200 years, stands break up at much younger ages. Pathological rotation age is about 70 years and economic rotation around 50 years (Burns 1983). Seed production begins early in balsam fir and good seed crops occur every 2-4 years after age 30. The cones shed their scales and mature seed in late August or early September. Effective seeding distance is about 30.4 m (100 ft)(Frank and Bjorkbom 1973). Balsam fir is very tolerant of shade. Seedlings can become established and grow for 6-8 years with only 10 percent of full sunlight, but best growth requires 45 percent or more of full sunlight. Under these conditions, seedlings can reach breast height in about 10 years.

Red spruce is a medium-size tree, reaching 30-61 cm (12-24 in) in diameter, and 18.3-22.9 m (60-75 ft) tall at maturity (Burns and Honkala, in press). Maximum age is reported to be about 400 years, but rotation ages in stands managed for sawtimber are about 75 years and for pulpwood about 50 years. Seed production may begin as early as age 15 in open-grown trees, but full crops are not common until after trees are 45 years old. Good seed crops occur every 3-8 years. Seedfall begins about October and is disseminated over an effective range of 61 m (200 ft)(Frank and Bjorkbom 1973). Red spruce is tolerant of shade and seedlings can become established with as little as 15 to 20 percent of full sunlight. Although seedling establishment is better in some shade, growth is better in the open where seedlings can reach breast height in about 13 years (Burns and Honkala, in press).

White spruce trees can reach more than 50 cm (20 in) in diameter and 30.4 m (100 ft) in height at maturity. Although white spruce is a relatively long-lived tree, rotation ages in stands managed for sawtimber are about 120 years and for pulpwood about 60 years. Seed production begins around age 30, but is not optimum until the trees are about 60 years old (Burns and Honkala, in press). Good seed crops are produced every 2-6 years and most seed is dispersed in September and October with an effective range of about 91 m (300 ft). White spruce seedlings are tolerant to shade and will survive many years of suppression and still respond to release. Under favorable conditions white spruce can reach breast height in 10-15 years.

The shade-tolerant upland spruce-fir forest types grow in both even-aged and uneven-aged stands. Recurring outbreaks of the spruce budworm (*Choristoneura fumiferana*) about every 40 years have killed many spruce-fir stands. Where mortality of mature trees is widespread, many seedlings become established and develop into even-aged stands. This is especially true in stands with a high percentage of balsam fir, the most vulnerable species to budworm damage and mortality. Spruce, especially red spruce, is not as vulnerable to budworm feeding, so damage in stands with high proportions of spruce is not as apparent (Blum and McLean 1984). White spruce may seed into abandoned agricultural land, especially in New England, creating essentially even-aged stands. Fire in upland spruce-fir types usually regenerates stands of pioneer hardwoods such as aspen and birch, but sometimes pine, and occasionally spruce stands, become established.

Recommended regeneration harvesting methods for the upland spruce-fir forest types are the single tree selection, group selection, the shelterwood system, and clearcutting (Johnston 1986, Blum and others 1981). The seed tree system of silviculture is not recommended because the shallow root system of spruce and fir render the residual trees vulnerable to windthrow.

The single tree selection system with relatively light harvests is most applicable in stands that already contain trees of many ages and sizes, and the shade-tolerant spruce and fir will respond by establishing ample regeneration when conditions are favorable (Frank and Blum 1978). The single tree selection system with a continuous high forest cover is desirable for esthetics and for maximum site protection, especially bordering streams, rivers, and other water bodies. Harvests at 5-20-year intervals allow the salvage of trees that might otherwise be lost to disease or insect damage. Growing space is more fully utilized in the vertical plane. Greater control over species composition reduces the balsam fir component, rendering the stand less susceptible to spruce budworm damage (Blum and others 1983).

Maintaining the desired mixture of tree ages, sizes, and species requires considerable planning and

skill. Harvesting in the single tree selection system is more difficult than in other silvicultural systems because the area to be covered for the allowable harvest is greater, and skill is needed to avoid damaging remaining trees. Wind damage is always a threat if too much volume is removed in one harvest. Selection of only the best and largest trees for removal, with little or no harvest of poor quality, small diameter trees constitutes high-grading and can deplete the best growing stock. Present day mechanical harvesters for the most part are not practical for selection harvests because of damage to the residual stand. Limited browse for deer is available under selection harvests, but good winter cover is provided for deer and good habitat for some bird species is provided (Blum and others 1981).

The group selection system, a variation of the single tree selection system, removes trees in small groups rather than individually, creating larger openings in the stand. The larger openings may make harvesting somewhat easier and provide somewhat better conditions for spruce-fir regeneration (Blum and others 1983).

The shelterwood system is applicable in stands that are even aged or where conversion to an even-aged stand is desirable, advance regeneration is inadequate, and the danger of windthrow is minimal as on protected sites with fairly deep soils. A healthy overstory where there are no serious insect or disease problems is also a prerequisite. One-third to one-half of the stand basal area should be removed in two or more harvests. Initial harvests should remove trees of less desirable species and quality, leaving the most desirable trees to provide seed. These harvests should open up the stand uniformly to allow seeding and subsequent regeneration under the shelter of the remaining overstory. The system allows some control over species composition by means of overstory manipulation and provides good growing conditions for the overstory. It may be 10-15 years, however, before spruce-fir regeneration has developed enough that the remaining overstory can be removed and some damage to regeneration will occur during the final harvest. It is more pleasing esthetically than clearcutting (Blum and others 1983) and in many cases is the most reliable system for regenerating spruce-fir stands; however, it is sometimes considered impractical from the harvesting standpoint.

Clearcutting is probably the most common silvicultural system used in the spruce-fir type today. It is a good method to apply in mature, overmature, or insect- and disease-ridden stands where partial removal would result in windthrow mortality, insufficient seed, or an unhealthy residual stand (Blum and others 1983). It is the best system for efficient use of mechanical harvesting.

Clearcutting, however, may leave the land with limited means for regeneration unless adequate advance regeneration (ca. 50-percent or greater stocking) is already present, a seed source is available from adjacent stands, or immediate planting is carried out. A harsh microenvironment can develop, making regeneration difficult, and a competitive cover of herbaceous plants and shrubs such as raspberries (*Rubus* spp.) may develop, requiring herbicide treatment if spruce regeneration is to be established in a reasonable time. Slash can smother advance regeneration, hinder the establishment of new seedlings, and increase fire hazard (Frank and Bjorkbom 1973).

Some of these disadvantages can be minimized by harvesting in alternate or progressive narrow strips, or in small patches. Strips as wide as half the height of border trees, or patches 0.4 ha (1 acre) or less in size, will provide shelter from the surrounding residual stand that should improve seedling survival by providing more moderate surface temperature and higher soil moisture. In a sense, these are variants of the shelterwood system (Blum and others 1983). Where environmental conditions are suitable for successful regeneration, dissemination of seed regulates the width of openings. For balsam fir, openings should be no more than 61 m (200 ft) wide; for red and white spruce they can be up to 122 m (400 ft) wide (Frank and Bjorkbom 1973).

Lowland Spruce-Fir Subgroup

The tamarack forest cover type grows on about 0.4 million ha (1 million acres) of commercial forest land in the Northeastern States. In the Lake States it is on 344,000 ha (850,000 acres), and in New England it is on 44,500 ha (110,000 acres), almost all in Maine. The type is most common on poorly drained areas, but it grows better on moist, well-drained, mineral soils with a shallow surface layer of organic matter (Burns 1983). Tamarack usually grows on wetter areas than black spruce, which is the most common associate growing with it in mixed stands.

Other trees growing with tamarack in mixed stands include northern white-cedar, balsam fir, black ash, and red maple. On transitional areas between swamps and uplands, paper birch and white pine are sometimes found in the mixture. Tamarack forest stands often have an understory of black spruce with a dense undergrowth of shrubs and herbs (Eyre 1980).

Almost all forest stands of tamarack were established by natural seeding. Seed production begins in trees about 40 years old and good crops are produced at 3- to 6-year intervals. Only about 5 percent of the seeds germinate, however, because of losses to rodents and diseases. The most favorable seedbeds are warm, moist mineral or organic soil without any shrub growth but with a light cover of grass or other herbaceous plants. Slow-growing sphagnum moss (*Sphagnum* spp.) often makes a good seedbed, but fast-growing sphagnum mosses may smother the tamarack seedlings (Burns 1983). Logging slash is detrimental to seedling establishment, but slash-burned seedbeds are favorable (Johnston 1975).

Tamarack seedlings can survive with a little shade the first 3 or 4 years, but they must have almost full sunlight for best growth. With abundant light, tamarack is one of the fastest growing conifers in the northern forest region (Burns and Honkala, in press). Because tamarack cannot tolerate shade, it must be dominant in mixed stands and is practically never found growing under the canopy of any species.

Mature tamarack trees average 15.2-22.9 m (50-75 ft) tall and 36-51 cm (14-20 in) in diameter at breast height on commercial forest land. Occasionally, some trees may reach 35 m (115 ft) in height and 102 cm (40 in) in diameter (Burns and Honkala, in press). Tamarack is a long-lived tree with stands reaching 150 or more years of age. Individual trees have been reported more than 300 years old. Rotation ages for managed stands, however, range from 90 years on the most productive sites to 120 years on the lower quality sites (Burns 1983).

The larch sawfly (*Pristiphora erichsonii*) is the insect most destructive to tamarack. Periodic outbreaks cause defoliation for several successive years, greatly reducing growth and killing many trees. The larch casebearer (*Coleophora laricella*) also defoliates tamarack and has caused mortality in some areas. Tamarack is affected by a number of infectious and noninfectious diseases (Ostaff 1986). Most of these do little damage and are not aggressive killers. The most significant disease affecting tamarack in New England is the European larch canker, caused by the fungus *Lochnellula wilkommii*. Although it seldom kills trees, it causes reduced growth and lessens wood quality. Permanent cankers on older trees cause stem distortion and weak points susceptible to breakage. The disease has brought about a quarantine on the export of tamarack logs or other tree parts in some areas in Maine in the 1980's. Fire easily kills tamarack, but fortunately, the areas where tamarack grow are normally wet enough to protect the trees from fire. Some trees are damaged or killed by porcupines (*Erethizon dorsatum*) feeding on the inner bark and girdling the main stem. Flooding damage caused by beaver (*Castor canadensis*) dams or road crossings result in mortality of some trees and slow growth for others. The wide root system of tamarack makes it fairly windfirm, but strong winds can uproot large trees growing in swamps or other areas where rooting is shallow.

Tamarack is a pioneer type, requiring open areas for seedlings to be established. Mature stands harvested by the clearcutting or seed tree cutting silvicultural systems provide suitable open areas for seedling establishment.

Tamarack stands with good seedbeds and little or no understory of shrubs or trees may be successfully regenerated by the clearcutting system in the winter after a good seed crop. This method, however, is almost certain to fail if used in years without a good seed crop. It is also a one-shot attempt with the current seed that has fallen or is dispersed in the logging operation. Otherwise, areas that have been clearcut must rely on seed from adjacent stands of mature trees or be artificially regenerated. Adequate seeding cannot be expected more than 61 m (200 ft) to the lee of the seed source and much less in other directions.

The seed tree cutting system provides a seed source by leaving about 25 well-spaced dominant seed trees/ha (10/acre). Another advantage of this system in mixed stands is that tamarack composition can be increased by leaving only tamarack seed trees (Burns 1983). Salvaging seed trees after seedling establishment may not be economical, but leaving them may serve other resource values.

Stands with an understory of black spruce seedlings may be converted to the black spruce type by clearcutting the mature tamaracks. Dense under-

growth of shrubs, however, will need to be controlled so that additional tree seedlings can be established after harvesting the mature tamarack. Stands with a dense undergrowth of shrubs can be harvested by the clearcutting system followed by broadcast burning the logging slash to consume it and to kill the competing shrubs. Tamarack logging slash is difficult to burn because it has no needles during the winter logging period. If other conifer slash is not adequate to carry a prescribed fire, the slash can be removed from the area by full-tree skidding and the shrubs can be killed by spraying with a suitable herbicide (Johnston 1975).

A combination of clearcut and seed tree strips may be used. A series of strips not more than 61 m (200 ft) wide are progressively clearcut toward (into) the prevailing wind. The next strip is clearcut after seedlings are well established on the most recently cut strip. The last strip is harvested by the seed tree system (Burns 1983).

The shelterwood system has limited value in the tamarack type. It is recommended only where the seed tree or clearcutting systems cannot be used. Composition of seedling stands will favor trees and shrubs that are more tolerant of shade than tamarack. The first or seed cut should leave 6.9 to 9.2 m^2/ha (30 to 40 ft^2/acre) of basal area in dominant and codominant trees (Burns 1983). The removal cut should be made as soon as the seedling stand is well established.

Selection harvesting methods are not suitable silvicultural systems for establishing tamarack seedlings. Thinning immature stands may be desirable on good sites to produce poles or sawtimber. Stand densities after thinning should be 18.4 to 20.7 m^2/ha (80 to 90 ft^2/acre) of basal area (Burns 1983).

The black spruce forest cover type grows on about 1.0 million ha (2.5 million acres) of commercial forest land with more than two-thirds in the Lake States. It is primarily found on lowland areas with peat (organic) soils more than 30 cm (12 in) deep, but the most productive forests are on transitional areas between lowlands and uplands with shallow organic to wet mineral soils (Burns 1983). Ground water that carries nutrients from upland mineral soils into the lowland increases productivity.

Black spruce grows in pure stands and in mixture with tamarack. Northern white-cedar and balsam fir are the other main trees associated with the black spruce type on lowland areas. On transition areas, black ash, red maple, balsam poplar, and white pine may be associated with the type. In northeastern Minnesota, jack pine is associated with black spruce, and in the Northeastern States, red spruce is a common associate. Stands on the most productive peat soils and on transition areas often have a dense undergrowth of tall shrubs. On less productive areas the undergrowth is more likely to be low shrubs, sedges, and feather mosses. Sphagnum moss is the predominant ground cover on the least productive areas (Burns 1983).

Natural seeding is the most important method to establish seedlings, but collecting seed and sowing it artificially is being done extensively in northern Minnesota. Good seed crops are produced by black spruce at 2-6 year intervals, beginning about age 40, but there is nearly a continuous supply of seed in the trees from the cones that persist and shed seed for at least 4 years (Johnston 1977a). All but the fastest growing sphagnum moss, which can smother seedlings, make good seedbeds, but feather mosses are poor seedbeds because they die and dry up when exposed to direct sun by harvesting mature trees. Burning or compacting the dead moss surfaces creates good seedbeds. Logging slash may cover good seedbeds and reduce chances for establishing a seedling stand.

Black spruce seedlings can survive in some shade and are rated shade tolerant. Best growth, however, is in the open. The most productive areas usually have a dense cover of tall shrubs and offer severe competition to the seedlings. Although some black spruce trees will eventually get above the shrubs on most areas, slow growth and mortality keeps productivity for the area below its potential.

Mature black spruce trees average 12.2-19.8 m (40-65 ft) tall and 20-25 cm (8-10 in) in diameter at breast height. Trees have been reported to reach 27.4 m (90 ft) tall and 46 cm (18 in) in diameter on the most productive areas (Burns and Honkala, in press). Black spruce is a long-lived tree, reaching 250 years. Rotation ages are usually between 60 and 150 years, depending on stand density and productivity of the soil (Burns 1983).

Dwarf mistletoe (*Arceuthobium pusillum*) is the most serious disease of black spruce, resulting in witches' brooms that stunt growth and eventually kill the tree.

Several fungi cause decay of tree butts in stands more than 100 years old growing on lowland areas, and in somewhat younger stands on uplands (Burns and Honkala, in press). Old-age trees with butt rot are susceptible to wind breakage, and the shallow rooting system of black spruce makes all mature trees vulnerable to uprooting on areas exposed to wind. The spruce budworm occasionally defoliates black spruce, especially in mixed stands with significant amounts of balsam fir or white spruce. Sometimes a few other insects attack black spruce, but serious damage to stands is uncommon (Burns and Honkala, in press). Trees are easily killed by rising water levels caused by beaver (*Castor canadensis*) dams or road crossings that block natural drainage. Black spruce is easily killed by fire, but losses on lowland areas are usually limited to years of severe drought conditions.

Many black spruce stands were established following a wildfire. The fire killed the trees, shrubs, and other plants, and the persistent cones on the killed trees released seed for several years onto the prepared seedbeds. Resulting stands of trees are all about the same age. Black spruce stands that escape fire for more than 100 years may become uneven aged, with young trees growing in scattered openings caused by the death of older trees (Burns 1983). Although black spruce is shade tolerant, it is not as tolerant as northern white-cedar or balsam fir, which will tend to replace it in uneven-aged stands on the more productive areas.

The clearcut silvicultural harvesting system is the most common method used in the black spruce forest cover type. Stands with dwarf mistletoe, dense undergrowth of tall shrubs, mostly feather moss seedbeds, or seedbeds likely to be covered with logging slash should be harvested by the clearcutting method, broadcast burned, and seeded naturally from a nearby stand of black spruce. If there is not a suitable stand of black spruce nearby, then the clearcut area should be sown with about 280 grams/ha (0.25 lbs/acre) treated with bird and rodent repellants. Black spruce stands with sphagnum moss seedbeds and no dwarf mistletoe or shrub problem can be regenerated by clearcutting and full-tree skidding so that all the logging slash is removed to the processing area. Seeds already on the ground plus those knocked off the trees during skidding will establish a new seedling stand (Johnston 1977a).

The seed tree silvicultural system is not recommended because the shallow rooted black spruce trees will most likely be lost to windthrow before they have served their purpose. Small areas where clearcutting is undesirable may be harvested by the shelterwood system if the trees are fairly windfirm and there is no dwarf mistletoe, no shrub competition, and plenty of sphagnum moss seedbeds. If logging slash is expected to be a problem, it should be removed from the area by full-tree skidding.

The selection silvicultural system may be used on areas where mature black spruce trees are relatively short and more windfirm. These stands are typically uneven aged and low density. On the more productive areas, selection cutting will change the composition of the seedling stand favoring northern white-cedar and balsam fir over black spruce (Burns 1983).

Thinning is generally not recommended in black spruce stands because of low economic return and risk of increasing wind damage (Johnston 1977a).

The northern white-cedar forest cover type grows on more than 1.6 million ha (4 million acres) of commercial forest land, with about half in the Lake States and half in New England. Largest areas of the type are in Maine and Michigan with more than 404 thousand ha (a million acres) each (Burns 1983). Much of the type grows in wet lowlands that have a strong flow of moderately mineral-rich soil water (Heinselman 1970). The most productive lowland areas have well-decomposed woody peat soils that are neutral or slightly alkaline. It also grows on seepage areas and limestone uplands. Pure stands sometimes develop on abandoned fields (Eyre 1980).

Northern white-cedar also grows in pure stands on lowland areas, but it is more commonly mixed with other lowland conifers. The trees most frequently mixed with cedar on the wetter areas are black spruce, tamarack, balsam fir, white spruce, black ash, red maple; and in New England and the mid-Atlantic States, red spruce. On the better drained areas associated trees include yellow birch, paper birch, aspen, balsam poplar, hemlock, and white pine (Burns 1983).

Seed production begins in trees about 30 years old with good seed crops every 3 to 5 years. Mature seed is dispersed by the wind from September to November with effective seeding distances less than 61 m (200 ft) under normal conditions. Rotten wood

is the most common place for seedlings to become established in undisturbed stands. On disturbed areas seedlings are aggressive on burns and on skid trails where the moss has been compacted and stays moist continuously. Seedlings do best on neutral or slightly acid soil, but will grow on slightly alkaline soil (Burns and Honkala, in press).

Natural seeding is the most common method of regenerating stand openings caused by wildfire or by harvesting. On poor sites with abundant sphagnum moss, layering is also a common method of reproducing northern white-cedar. Branches that are partially covered with moss develop roots and become a new tree. Sowing seed or planting seedlings have not been widely used regeneration methods for forest stands.

Northern white-cedar is tolerant of shade, but after the first few years seedlings grow best with half or more of full sunlight. Drought, smothering, and rodents are the major causes of seedling mortality (Burns 1983). Browsing by white-tailed deer (*Odocoileus virginianus*) can prevent seedling establishment, especially in deeryards. Snowshoe hares (*Lepus americanus*) also browse seedlings heavily in some areas in the Lake States.

Northern white-cedar grows more slowly and is shorter than its associates. Mature trees are 12.2-15.2 m (40-50 ft) tall and 30-61 cm (12-24 in) in diameter. White-cedar is long lived, reaching ages of 400 years or more. Recommended rotation ages for growing small products in managed stands ranges from 70 to 100 years, depending on site quality. Recommended rotation ages for growing sawtimber and other large products range from 110 to 160 years (Johnston 1977b). White-cedar stands managed for deer shelter should have rotations at least as long as those recommended for sawtimber.

The most serious threat to white-cedar is overbrowsing by deer and hare. Sometimes porcupines feed on the foliage or kill trees by girdling. White-cedar is relatively free of any serious insect or disease damage. Although the tree is easily damaged by fire, the risk of wildfire is low on most areas where white-cedar grows.

Many of today's even-aged stands were established on burned areas. Without a major disturbance such as fire, however, the type is very stable and will develop an uneven-aged stand. Because cedar is long lived and tolerant, it can perpetuate itself by establishing seedlings in small openings created throughout the stand by occasional mortality or by partial cutting. Although uneven-aged stands are common, they are not as valuable for timber and deeryards as even-aged stands. Uneven-age management should thus be limited to areas with slow-growing trees (poor sites) that are not tall enough for good deer shelter and where only the largest trees are merchantable (Burns 1983).

Clearcutting in strips or patches is the recommended silvicultural system for managing even-aged stands of northern white-cedar (Johnston 1977b). The strips should not exceed 61 m (200 ft) in width so that all seedbeds are within effective seeding range. The last strip should be cut by the shelterwood system to ensure adequate seeding. Shelterwood strips with 13.8 m^2/ha (60 ft^2/acre) of basal area will adequately seed the area within 10 years.

The shelterwood system may also be used in stands on small areas where clearcutting is not suitable. An advantage of the shelterwood system in mixed stands is that composition of cedar may be increased in the reproduction stand by removing seed-producing trees of other species in the first cut. Seed tree cutting is not recommended for the northern white-cedar type.

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Silviculture of Southern Pines

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Perspective on Southern National Forests

In contrast to the national forests west of the hundredth meridian, 91 percent of southern national forest land was purchased. Acquisitions were under the Weeks Act of 1911 and a number of subsequent acts. These were forest lands from which one or more timber harvests had been made, or they were wornout and abandoned farms. The lands are diverse by nature of soils and terrain, and by land-use history prior to their acquisition for the National Forest System. The large number of species of trees and shrubs native to the South adds further to the complexity of southern forests.

In many southern national forests the Federal ownership is fragmented. Intermingled private lands may constitute as much as 70 percent of the total land within their boundaries. The average for the region approximates 50 percent. Overall, national forests contain 5.8 percent of the commercial forest land in the region (USDA Forest Service 1982). Many of these national forests have been in federal ownership less than 60 years and forest stands have not yet reached desired species composition or stocking levels.

"Original" and Subsequent Southern Forests

Early writers of the colonial period reported extensive pine and mixed pine-hardwood forests. Lightning fires and fires set by Indians burned large areas at frequent intervals. Indians reputedly used fire to improve hunting conditions. The early white settlers continued the use of fire in landclearing, to rid the woods of snakes and insects, and to "green up" the range in the spring and thereby control the movement of their cattle. Burning to reduce insect populations was used until comparatively recent years by cotton farmers in their struggle against the boll weevil.

Natural wildfires and other catastrophic occurrences perpetuated most of the southern pines because of their inherent resistance to fire and because fire killed the small hardwood trees and shrubs that competed with the pines for light, moisture, and nutrients. Longleaf pine (*Pinus palustris*), for example, is considered a fire subclimax by ecologists and can be perpetuated indefinitely by the proper use of fire. Pines cast less shade than equivalent hardwood stands and thus it is more likely that advanced pine regeneration will become established under a pine overstory. Southern pines cannot be successfully regenerated routinely under full hardwood canopies. The ecological requirements of southern pines and their pioneering nature led to the presently extensive southern pinery. These stands were originally established through natural fire and catastrophe and, subsequently, by the abandonment of agricultural land.

Many southern pine sites, due to low nutrient levels and lack of soil moisture, will not produce merchantable hardwoods in a reasonable time (50 years) nor on an economically sound basis at any age. These sites can produce merchantable pine timber, however, if properly managed. Many southern pine

sites are low in wildlife habitat values, but such values can be enhanced with good management.

Agriculture Handbooks 654, "Silvics of North America" (Burns and Honkala, in press), and 445, "Silvicultural Systems for the Major Forest types in the United States" (Burns 1983), and the 60 years of combined experience of Burns and Barber in silviculture, tree breeding, and research administration in the South, provide the basis for this paper on the silviculture of southern pines.

General Silviculture Considerations

The major southern pines, longleaf, shortleaf (*Pinus echinata*), slash (*P. elliottii* var. *elliottii*), and loblolly (*P. taeda*), are intolerant of shade. They must have full sunlight from above to achieve optimum growth. Protection from wildfire has permitted the encroachment of hardwood trees and shrubs in pine stands and it is this competition for light, nutrients, and moisture that reduces the opportunity to establish pine regeneration regardless of the silvicultural system used.

Successful pine regeneration requires abundant light and exposed mineral soil for seed germination and seedling establishment. Under conditions ideal for pine regeneration, too many seedlings may become established, requiring either precommercial thinning or the sacrifice of growth as nature compensates for overcrowding by death. Even where planting is used, competition, especially for light, must be controlled.

Managed southern pine stands require control of stocking from establishment to harvest. Yield of wood, especially the size of trees, is affected by stocking levels. Stocking maintained at moderate levels can produce high rates of wood on large trees and at the same time provide good production of food plants and forage for wildlife. Where wildlife such as quail, turkey, or deer is favored, good management can provide quality habitat.

A properly managed forest will provide a diversity of age classes. This favors diversity of wildlife and, where properly designed, enhancement of esthetic values.

Forest diversity is high in southern national forests because of the many private tracts intermingled within national forest boundaries. Southern terrain is quite varied with respect to topography, soils, and quality. Drainages that disect it provide stream bottoms, stringers along stream courses, and coves that can be managed for hardwoods or mixtures of hardwoods and pines. Soils differ and site quality varies over short distances as a consequence of past land-use practices and erosion. Even in the slash pine flatwoods, a few centimeters (inches) in elevation affects the water table and changes the plant community.

Diversity is everywhere in the South. This means that each stand must be managed individually. General prescriptions should not be broadly applied. The shape and size of each stand is delineated by the history of the stand and the history of land use on the site. The treatment chosen and the area to which applied are functions of these histories and, on the 54.6 million ha (135 million acres) owned by nonindustrial private forest landowners in the South, the highly variable objectives of these owners affect the choice of treatment. Maintenance of healthy stands reduces stress and subsequent predisposition to attack by insects and diseases.

Considerations for Intensive Timber Production

Intensive management of selected sites will provide substantial increases in wood and fiber production to meet national goals. This intensification on some sites will reduce total acreages required and thus, fragile and marginal sites can be avoided and stands can be managed jointly for more than one purpose, for instance, timber, wildlife, water, and recreation. The southern pines will be called upon to meet a greater share of future demand for all of these purposes and for an increasing share of the wood products presently provided by old-growth western forests.

Diversity of terrain, soils, site quality, and plant communities requires that prescriptions for each stand be made on an individual basis by qualified foresters, soils scientists, hydrologists, wildlife biologists, and professionals in related disciplines. Silvicultural practices must be monitored and adjusted

continuously as new knowledge becomes available from research.

A major opportunity to enhance productivity is available under intensive management through the use of genetically improved trees. More than 0.4 million ha (1 million acres) have been planted or seeded to forest tree species in the 12 Southern States each year for the past 15 years. In 1984, that number approximated 769 thousand ha (1.9 million acres), and virtually all were planted with southern pines (USDA Forest Service 1985). Fully 60 percent of seedlings currently being planted in this region are genetically improved pines.

The use of genetically improved forest planting stock is an essential element in the future success of this expanding tree planting program. The major value of tree improvement is realized when intensive management and tree improvement are applied on carefully selected areas. By employing genetically improved southern pine planting stock as an integral part of the intensive management effort in the South, a 10- to 20-percent increase in volume and a similar increase in quality characteristics has been realized from improvement efforts in the first generation. Second and third generations of genetically improved planting stock will certainly further increase these yields. Furthermore, by increasing the inherent resistance to diseases such as fusiform rust (*Cronartium quercuum* f. sp. *fusiforme*), pitch canker (*Fusarium moniliforme* var. *subglutinans*), and brown spot needle blight (*Scirrhia acicola*), the productivity of major species such as loblolly pine, slash pine, and longleaf pine can be increased. In fact, high-hazard sites caused by fusiform rust disease may once more become fully productive. Within the last 35 years, the basic concepts of modern forest genetics and tree improvement have been developed, tested, and applied successfully throughout the South.

To optimize wood production in relation to other resource values, appropriate control of stocking is needed throughout the rotation. Good stocking control will make it possible to realize maximum wood from each acre while incorporating practices that provide improved wildlife habitat and range, as well as improved recreational and watershed values. For example, moderate stocking levels in pole and sawtimber stands permit high forage production for grazing and browsing animals. Normal plant succession on site-prepared lands provides abundant seeds and forbs during early years of the stand and a corresponding increase in the populations of quail, dove, and other birds. Browse available for deer is also greatly increased (Burns and Hebb 1972).

Major Southern Pine Types

The major pine types of the South are of both biological and silvicultural interest. They lend themselves well to management for water, wildlife, recreation, esthetics, and range as well as for wood products. Descriptively, the primary forest types include the four major southern pines both singly and in mixture and each of these in mixture with hardwoods, principally oaks: Society of American Foresters forest cover types 70 longleaf pine, 71 longleaf pine-scrub oak, 75 shortleaf pine, 76 shortleaf pine-oak, 80 loblolly pine-shortleaf pine, 81 loblolly pine, 82 loblolly pine-hardwood, 83 longleaf pine-slash pine, 84 slash pine, and 85 slash pine-hardwood (Eyre 1980).

The geographic range of the southern pine species that comprise these types is varied, yet they share a similar climate. Singly, or in combination, their range extends from the Barrens of New Jersey southward through the mountains of Virginia, West Virginia, Kentucky, Tennessee, and the Carolinas through the foothills, Piedmont, and Coastal Plain to the flatwoods and sandhills of Florida; westward across the yulf Coastal Plain into eastern Texas and Oklahoma; northward to the Plateau and Highland Rim of Tennessee; and into the Ozarks of Arkansas and Missouri. Botanically, their ranges overlap in the South. Some frequently occur in mixed stands, yet each species is adapted to a slightly different environment where it may grow almost exclusively. Common to this diversity of soils and topography is a frost-free season ranging from 140 to more than 300 days with precipitation ranging from 1020 to 1750 mm (40 to 69 in) and averaging about 1270 mm (50 in) annually (Burns and Honkala, in press).

The southern pines also share many silvicultural characteristics that distinguish them from their upland hardwood associates. Southern pine seeds, with the exception of those of longleaf pine which are heavy, are characteristically light in weight and winged. Consequently, they may be borne on the wind for distances exceeding 30.5 m (100 ft). Pine seeds germinate best on exposed mineral soil in partial shade, but once seedlings become established they

require full sunlight for optimum growth and development.

In contrast, seeds of most upland hardwood associates are comparatively heavy, are disseminated principally by gravity and animals, and will germinate and grow amid the litter and shade of overtopping trees. Because of differences in light requirements for optimum growth, most southern pines are classified as intolerant of shade while many of their hardwood associates are considered to be intermediate in tolerance to tolerant of shade. Pines and hardwoods also differ in their susceptibility to damage by fire. Hardwoods suffer most. Left undisturbed by fire, and without continued manipulation to ensure the succession of pine, the pines will eventually give way to a slower growing, more shade-tolerant hardwood climax forest.

As the ecological requirements of pines and hardwoods differ, so do the methods that can be used in establishing, manipulating, and regenerating them to meet prescribed management objectives for pure stands of pines and mixed stands of pines and hardwoods.

Oak-Pine Forest Types

There are more than 14.2 million ha (35 million acres) of the oak-pine type in stands scattered throughout the Southern and Eastern States (USDA Forest Service 1977). As might be expected, there is a considerable variation in climatic conditions over such a large area. In the northeastern and western portions, the growing season averages about 160 days, precipitation averages from 940 to 1015 mm (37 to 40 in), and mean temperature approximates 8.9 °C (48 °F) annually. At the other extreme, along the gulf coast, precipitation averages about 1525 mm (60 in), mean temperature averages 21.1° C (70° F) annually, and the growing season averages 230 days (Graney and Kitchens 1983). Nearly 70 percent of these forested acres are controlled by nonindustrial private landowners.

The oak-pine forest type represents a transitional stage of the successional pattern from a pine-dominated to a hardwood-dominated climax forest. Although it may include any species of southern pine, it is most commonly associated with loblolly pine and shortleaf pine. Hardwoods include scarlet oak (*Quercus coccinea*), northern red oak (*Q. rubra*), southern red oak (*Q. falcata* var. falcata), and chestnut oak (*Q. prinus*), and lesser amounts of yellow-poplar (*Liriodendron tulipifera*) and sweetgum (*Liquidambar styraciflua*) in a proportion of more than 50 percent oak to at least 25 percent pine. The successional trend favors shade-tolerant hardwoods that become established in the understory. Harvest of mature oaks and pines accelerates the transition.

The silvicultural objective for timber production on the shallow soils and eroded uplands is to increase the proportion of the fast-growing and more commercially desirable pine components among the slow-growing, low-value oaks. Hardwoods are favored on the more productive sites stocked with species having the potential to grow high-value products.

All of the pines and yellow-poplar of the oak-pine type are relatively intolerant of shade and, along with northern red oak, which is slightly more tolerant, may be regenerated under even-aged management. The clearcut, shelterwood, and seed tree methods of harvest cutting have been used successfully to regenerate pines. To ensure optimum stocking and growth of pines, however, clearcutting, followed by site preparation, hardwood control, planting, or precision seeding is recommended. Application of this silvicultural system results in more uniform stocking and spacing and also affords the only practical means of introducing genetically improved stock. This may prove to be particularly important where and when resistance to a particular disease or disease complex is a critical factor. It also allows seeding or planting of disease-resistant loblolly pine on sites where littleleaf disease (*Phytophthora cinnamomi*) of shortleaf pine is a problem, and the use of shortleaf pine along the northern portion of the range where loblolly is susceptible to snow and ice damage, and in southern areas where loblolly is prone to infection by fusiform rust (Graney and Kitchens 1983).

Uneven-aged management in which single tree or group selection is used favors shade-tolerant hardwoods. Although group selection cuttings have been used to regenerate pines in the oak-pine type, they must be accompanied by vigorous hardwood control, which is expensive to apply on small scattered areas and which poses the threat of harvesting damage to the residual stand. Single tree selection cutting does not provide enough light for the successful establishment and growth of intolerant pines and hardwoods. However, if timber production is not a management

objective and the transition from pine to slow-growing oaks and hickories is of little concern, single tree and group selection cutting can be used to maintain a permanent forest canopy. This however, will restrict species diversity and the productivity of the site for the generally more valuable,intolerant pines and hardwoods. These silvicultural systems also are detrimental to habitat values for some wildlife species.

Loblolly Pine, Shortleaf Pine, and the Loblolly-Shortleaf Pine Forest Types

Loblolly and shortleaf pines are light-demanding (intolerant) species. They grow best in full sunlight in relatively pure stands and in mixture on 50 million acres of commercial forest land in the Eastern United States (USDA Forest Service 1982). The type occurs on a wide variety of soils and sites including deep, moist, well-drained soils as well as shallow, eroded soils with textures ranging from heavy clays to loamy sands. Associated with the pines of this type are sweetgum and the more shade-tolerant gums (*Nyssa* spp.), oaks (*Quercus* spp.), hickories (*Carya* spp.), and maples (*Acer* spp.)(Brender 1973). These often form dense understories in pine stands and the beginning of succession to the oak-hickory climax type as pines are harvested.

In nature, loblolly pine predominates and grows fastest on moist sites. Shortleaf pines tend to prevail on thin, dry, infertile soils such as those found in portions of the Piedmont and in the mountains of Arkansas. Shortleaf pine also grows north of the natural range of loblolly pine.

The loblolly-shortleaf type can be regenerated using either artificial or natural means. All of the silvicultural systems are applicable in this forest type (Baker and Balmer 1983). Selection of any one is closely dependent upon the resource value to be emphasized and management's objectives. Clearcutting, seed tree, shelterwood, or selection silvicultural systems may be employed to obtain natural reproduction provided that competition from understory hardwoods is controlled, the cutting is timed to take advantage of a good seed crop, and the openings provided are large enough to allow intolerant species room to develop and grow. Crops of seed adequate for restocking occur at intervals of about 3 to 6 years and bumper crops occur every 3 to 11 years.

Timing of cultural treatments can be critical because the interval between cone ripening and cone opening is only about 4 weeks. Without a mineral seedbed and an adequate seed crop, shrubs, herbaceous plants, and sprouting hardwoods rapidly reoccupy the site, may necessitate costly retreatment, and can cause a possible delay of several years before another seed crop adequate to stock the area occurs.

Clearcutting is a silvicultural system that affords several advantages over other methods of regenerative cuttings in that it enables use of prescribed fire, broadcast application of herbicides, and heavy site-preparation equipment without danger to a residual stand. Artificial methods of regeneration, including planting genetically improved trees, can be employed to avoid loss of time for restocking. Planting of genetically improved seedlings also affords an opportunity to introduce trees with superior qualities to act as progenitors of subsequent rotations.

The shelterwood system has been most successful in the eastern part of the range where summer rainfall is usually adequate for good first-year survival and where some seed is produced almost every year. With a shelterwood, too many pines are left standing for efficient operation of large harvesting and site-preparation equipment without damage to the residual stand. Prescribed burning is the most practical method of site preparation (Lawson and Kitchens 1983). Timing harvesting and site preparation with seed production is usually the key to success.

With the seed tree system, proper manipulation of the seed supply and of seedbed conditions is essential for success. Well-stocked stands usually result if adequate seedfall occurs within a year after the seedbed is prepared. Prescribed burning, which can be done before or after the main stand is cut, requires great care. The fires must be hot enough to kill back the hardwoods but not so intense that the seed trees are damaged. Abundant seed crops occur at infrequent intervals. Therefore, selection of large, well-spaced pines with a history of good seed production and evidencing developing conelets is important.

The selection system may have special utility in or around recreation areas, where esthetic values are important, and on highly erosible sites. Selection cutting has been used primarily in understocked stands where removal of a few pines and the control of adjacent hardwoods often create openings large

enough for reproduction to become established. The system has not been applied successfully on a wide scale in fully stocked stands because openings are too small for practical mechanical scarification and there is a danger that fire for seedbed preparation will kill pine seedlings in nearby openings. Broadcast methods of stand treatment ordinarily cannot be used; trees must be considered individually or in small groups. The selection system requires frequent stand entries, removal of mature, low-quality, and cull trees at each entry, and is expensive to apply if a good management job is done. In addition, loggers must use extra care to avoid damage to future crop trees.

Longleaf Pine and Slash Pine Forest Types

Wildfire played an important role in establishing and maintaining the range of the longleaf pine and slash pine forest types. Before fire protection, slash pine forests were confined to the poorly drained portions of the middle and lower Coastal Plains from South Carolina to eastern Louisiana. The more fire-tolerant longleaf pines occupied the drier sites in a broader belt along the Coastal Plain from Virginia to Texas and extended northward into the Appalachian foothills of Alabama and Georgia. The effectiveness of modern fire protection has enabled slash pine and loblolly pine to seed into many former longleaf pine sites. It also enables hardwoods and shrubs to proliferate. The type is temporary in that burning destroys slash pine regeneration and the exclusion of fire allows hardwoods to encroach and eventually dominate the overstory. The longleaf pine-slash pine type is most commonly found in the flatwoods of Georgia and Florida. Its range has been artificially extended into western Louisiana and east Texas by the widespread planting of slash pine (Eyre 1980).

There has been a decrease in the acreage ofT longleaf and slash pine over the past decade. Currently, the combined area occupied by these two types approximates 7.4 million ha (18.3 million acres)(USDA Forest Service 1977). It extends from southern Virginia in the north to south-central Florida then westward to east Texas in the Atlantic and Gulf Coastal Plains.

The climate is variable over this range. In general, it is characterized by warm, moist summers and mild winters. In northern areas annual temperatures average about 17.2 °C (63 °F) and precipitation averages 1120 to 1270 mm (44 to 50 in). The growing season varies from 210 to 240 days. At the southern extreme the mean annual temperature is 23.3 °C (74 °F), rainfall averages about 1650 mm (65 in) along the Gulf, and the growing season may exceed 300 days (Boyer, in press; Lohry and Kossuth, in press).

Longleaf and slash pine differ in silvical characteristics such as seedling habit and juvenile growth, but the silvicultural prescriptions for both are similar. Even-aged management is recommended forL longleaf pine because of intolerance to shade, the slow growth of regeneration in the presence of an overstory, the need to control brown spot, and the need to reduce hazardous fuels by prescribed fire.

Longleaf pine is not a prolific seeder and produces good seed crops only at 5- to 7-year intervals (Schopmeyer 1974). The seeds are heavy and, although they have large wings, they are not widely disseminated. For these reasons, it is unlikely that an adequate seedcatch will result with any consistency over a wide area using the seed tree method. Shelterwood is the preferred method for use with longleaf pine because it provides a dependable seed supply, reduces regeneration time, and lowers the incidence of infection and severity of brown-spot needle blight. Longleaf pine has the reputation of a species difficult to plant. Historically, this has been true but techniques for successfully plantingo longleaf pine have been developed. Where these techniques have been carefully applied, survival of planted longleaf pine has been as good as, or better than, that of many other southern pines. Nevertheless, it is because of this reputation that natural regeneration is often favored over seeding and planting. Protection from livestock is essential once the seedling stand is established. Even light-to-moderate grazing by cattle causes mortality and reduces growth of surviving seedlings. Hogs are particularly harmful; they feed on the roots and can completely destroy a seedling stand (Boyer, in press).

Successful natural regeneration of slash pine by any of several silvicultural methods depends upon an adequate supply of seed, an exposed mineral soil seedbed, and control of competition. Slash pine is a relatively good seed producer. Some seeds are shed each year and heavy cone crops occur about every 3 years. Crown release by thinning is one of several methods that can be used to stimulate cone production. Site preparation by fire or mechanical means improves the seedcatch by exposing a mineral seedbed and controlling understory vegetation. The

seed tree and shelterwood silvicultural systems are recommended for extensive low-cost culture. Clearcutting followed by mechanical site preparation and either seeding or planting is the usual system applied for intensive management. Artificial regeneration on a prepared site has the added advantage of reducing the time needed for stand establishment, of controlling stocking, and of providing an opportunity to establish genetically improved pines. For these reasons, owners of extensive acreages of slash pine prefer to clearcut, prepare the site mechanically or with chemicals, and then direct seed the area or plant it with nursery- or container-grown stock (Shoulders and Parham 1983).

Slash pines are intolerant of shade. Even-aged management and silvicultural systems that foster even-aged stands are most widely used to prevent suppression of regeneration by overstory trees. Even-aged stands can be carefully burned for fire-hazard reduction and improvement in wildlife habitat and forest range. Under even-aged management trees may be harvested in one operation, and by so doing preventive measures may be taken to reduce the incidence of annosus root rot (*Heterobasidion annosum*). The use of fire for protection and enhancement of wildlife and range values is not feasible in uneven-aged stands because when trees of all sizes are present, the likelihood that a ground fire may develop into a killing crown fire is greatly increased.

Even- Versus Uneven-aged Management and Multiple-use Objectives

Even-aged silvicultural systems lend themselves well to management for a wide range of mutiple-use objectives and for rehabilitating exploited and mismanaged stands. Because more of a stand is subject to manipulation at any one time under even- than uneven-aged management, greater opportunities exist for making improvements rapidly. Alterations in the composition and constitution of forested stands tend to be dramatic under intensive, even-aged management and nature's response is equally so. Ground cover burgeons from dormant seeds on-site and from introduced, windblown seeds. A diversity of plants and animals results. As the successional process advances and the composition and constitution of understory plants change, so does the environment for wildlife and grazing animals. Animals are always present, but their numbers and species vary in response to the constantly changing plant community, its diversity, and the ability of the plants to provide food and/or shelter.

Impacts of even-aged silviculture on water, recreation, and esthetics are closely associated with the degree of vegetative manipulation. Water quantity and water quality depend upon many things, including how severely the existing plant community is altered, method of logging, application of sound engineering principles, skill of the manager, proximity to natural watercoarses, and management's objectives. When these are prudently applied with due regard for all soil, plant, and wildlife values, there need be no meaningful or apparent decline in water quality regardless of the silvicultural system applied.

If diversity is truly desirable, then breaks in the forest continuum should add to, and not detract from, esthetic values. It has only been in comparatively recent times that principles of landscape architecture have been accepted as part of forest planning, harvesting, and management. Properly applied, these principles should go a long way in allaying objections based on esthetic considerations to even such esthetically traumatic practices as clearcutting.

Recreational activities exclusive of esthetics are widely divergent. Certainly, hiking and camping are not compatible with logging debris, but hunters and bird-watchers may seek out such areas for the diversity of plants and cover they contain and the abundance of wildlife that such conditions promote. Areas bordering recently harvested forested stands are particularly rich and varied in the variety and abundance of plants and animals they contain regardless of whether the border results from uneven- or even-aged management. In this regard, mixed pine-hardwood stands offer the greatest diversity because of the variety of seeds provided by the parent stand.

In preparing management plans and harvesting and cultural schedules, it is important to consider the size of stands treated and the overall mosaic of age classes and timber types. Wildlife should find the variety of annual habitat needs in close proximity; hikers and forest observers should be able to range widely and not encounter large areas of undesirable conditions to transit. Grazing and browsing animals should be able to find a continuum of satisfactory forage among stands without unacceptable distances in between. In many cases on southern national

forests frequent consultations with adjacent and intermingled landowners can enhance forest values through coordination of harvesting and cultural practices. Good forest management and silvicultural prescriptions can best meet the goals of the National Forest System.

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Silviculture of Western Inland Conifers

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Introduction

Forests of the inland Western United States blanket the foothills and mountains with a wide array of tree and understory species, provide a variety of resource values, and are the mainstay of many communities throughout the West. Timber products from these forests have been a key factor in the settlement, development, and economy of the West for the past century. Now, the increasing demand for associated resources such as forage for wildlife and domestic livestock, water, recreation, and esthetics has added new dimensions to the management of these forests. Forest managers must select the silvicultural practices that will enhance the value of the important resources on any given area as well as reduce insect, disease, and animal problems. That is the challenge for multiple-use silviculture of western inland conifers as we approach the 21st century.

Western Inland Conifer Zones

Forests of the inland Western United States occupy a mountainous landscape. Lands between the mountain ranges are typically occupied by grasses and shrublands. The mountains themselves strongly influence the environment and the forests they support, causing significant changes over relatively short distances, typically ranging from semiarid, warm foothills in the lowlands to cold tundralike conditions at high elevations.

The trees, associated vegetation, and animal life have adapted to each other and the various environments that occur on a range of mountains, or even a single mountain or plateau. Because the inland West is subject to seasonal drought, forest adaptations include responses to wildfires that occur at different intervals and intensities in the diverse mountain environments. Couple this with various insects, diseases, weather, and man-induced disturbances and we have very complex and dynamic ecosystems.

Silvicultural treatments and their influence on resource values depend on the potential of the site to produce any given resource and on the demand for these resources. Obviously, the inland West encompasses a wide variety of ecosystems and resources that do not necessarily behave in similar fashion. Therefore, responses to management techniques are discussed under three groupings or zones: lower slopes and foothills, montane, and subalpine. Cover types that group commonly associated species together will also be used to describe these forests (Eyre 1980). In general, the lower slopes and foothills zone is low, the montane is middle, and the subalpine is high elevation in relation to each other. This corresponds in most cases to dry-warm at the lower elevation and cold-moist at the higher elevation with a gradient in between. In spite of these differences, the three zones have some characteristics in common that influence their potential usefulness for various resources.

Nearly all forests of the inland West are composed of conifers that have regenerated from seed dispersal naturally from immediate or adjacent areas. Much of the discussion of silviculture in this paper will focus on methods of obtaining natural regeneration following some type of harvest cutting in which the older

forest has been partially or totally removed. Artificial regeneration, involving planting of seedlings and direct-seeding, will also be discussed. Tending the young forest after it is established will also be described.

To assist the silvicultural prescription process, a number of vegetation classifications have been developed for the inland West. This includes the rather broad classification of forest cover types (Eyre 1980) and the far more detailed ecological habitat types, now mostly completed for much of the inland West. The former classification is based on the predominant tree species covering the landscape at the present--the latter is a more detailed classification of the tree and understory vegetation species that would eventually occupy an area. An example of this classification method is that developed for Montana's forest (Pfister and others 1977). The latter classification is a very useful tool but, because it is largely site specific, is beyond the more general scope of this paper.

The regeneration cutting methods discussed in the following sections will include individual tree and group selection for uneven-aged management and seed tree, shelterwood, and clearcutting for even-aged management. Thinning effects will be described for immature forests.

Terminology, species names, and silvicultural descriptions in this paper will be based largely on the standard references in this field (Society of American Foresters 1971, 1981; Little 1979). Because of the importance of some ecological terminology, the following definitions are important. The term succession will be used to describe a gradual replacement of one community of plants by another. This is closely related to shade tolerance or the ability to regenerate and grow under shaded conditions. Early successional species that regenerate soon after a major disturbance such as fire and harvest cutting generally require much sunlight and are referred to as seral species. Late successional species are able to regenerate and grow under shade, gradually replacing the early successional or seral species. As a result they are called climax species.

Lower Slope and Foothill Forests

This zone has moderate values for many resources over extensive areas in the inland West. Silviculture must be multiresource oriented with emphases on growing healthy stands of trees that concurrently provide good conditions for livestock, wildlife, and recreational opportunities. Balancing these multiple values through judicious management is a significant challenge to silviculturists.

This zone includes all or portions of the cover types discussed in Agriculture Handbook 445 (Burns 1983)--Northwest ponderosa pine and associated species, ponderosa pine, Rocky Mountain Douglas-fir, Southwest ponderosa pine, Interior ponderosa pine in the Black Hills, and pinyon-juniper.

Tree species include:

Juniperus californica
California Juniper

Juniperus deppeana
Alligator Juniper

Juniperus monosperma
One Seed Juniper

Juniperus occidentalis
Western Juniper

Juniperus osteosperma
Utah Juniper

Pinus contorta
Lodgepole Pine

Pinus edulis
Rocky Mountain Pinyon

Pinus flexilis
Limber Pine

Pinus monophylla
Single Leaf Pinyon

Pinus ponderosa
Ponderosa Pine

Juniperus scopulorum Rocky Mountain Juniper	*Pseudotsuga menziesii* var. *glauca* Douglas-fir
Pinus cembroides Mexican Pinyon	*Quercus* spp. Oaks

These are the warmest and driest of the western forests. Ponderosa pine, Douglas-fir, limber pine, and various species of juniper or pinyon pine dominate the potential natural vegetation. Even in the absence of wildfire or other disturbance, these trees tend to replace themselves as the mature stands gradually die out.

Historically, wildfires burned through these stands very frequently, generally in the range of 5 to 30 years. This frequency prevented buildups of fuel and consequently most fires were of low intensity (Schmidt 1981). Ponderosa pine and, to a lesser extent, Douglas-fir develop thick, fire-resistant bark as the trees mature. As a result large trees commonly survive fires, but their younger counterparts, particularly those with low crowns, usually succumb to fire. Open, parklike stands are perpetuated by frequent low-intensity fires. Early photographic records document the prevalence of these conditions when the West was being settled (Arno and Gruell 1983).

In the last 50 years, effective fire control has resulted in the establishment of dense multilayered stands of younger trees--often Douglas-fir--below the canopy of the larger and older trees. Also, stands of ponderosa pine, pinyon pine, and junipers have become denser and, in some parts of the West, have extended their range into areas that formerly supported only grasses.

Because the lower slope areas adjoin grasslands, grazing of these stands by domestic livestock has been a major use from the time of earliest European settlement. Grazing, while it can be harmful to seedling trees, has also reduced the competition for moisture by the grasses. As a result, trees have become established on some heavily grazed sites that formerly were considered grasslands.

Timber has been extensively harvested from this zone since the times of early settlement. The building of railroads, towns, and cities during this era of expansion in the United States depended heavily on these old-growth, easily accessed stands of timber. Towns and cities generally were established in the warmer valley areas and the adjoining forests became convenient and valuable sources of timber and fuel. This also affected the stands we have today because most of the larger, older trees were removed, and dense stands of smaller, lesser value trees remained in place. In addition, some of these residual stands were comprised of shade-tolerant species that are far more subject to insect and disease problems.

The primary commercial species in this zone is ponderosa pine. It has traditionally been a high-value species, particularly when mature, but relatively low volume-per-unit-area and the warm-dry conditions over most of its range limit the choice of silvicultural methods. High-cost silvicultural treatments, such as tree planting and use of genetically improved trees, are economically feasible on the better sites but questionable on the poorer sites within the zone (Burns 1983). Productivity of sites in this zone, in terms of volume growth, typically ranges from less than 1.4 to more than 3.5 m^3/ha (20 to more than 50 ft^3/acre) per year if fully occupied with trees.

In terms of commercial species, Douglas-fir is next in importance to ponderosa pine in the moister portions of this zone. Because of greater shade tolerance than ponderosa pine, it tends to replace ponderosa pine on shaded, less-disturbed sites in this zone. Douglas-fir is a particularly unique species because of its broad ecological amplitude--it can be found at low, mid, and high elevations from the southern to northern borders of the United States. As a result, on most sites in this zone it behaves as a late successional (relatively shade tolerant) species and in zones above this behaves as an early successional (relatively shade intolerant) species. In this zone, seed crops are normally sporadic, with good crops every 3 to 4 years and light crops in the intervening years (Burns 1983). A number of physical and biological factors affect cone and seed production, including late frosts, insects, and animals such as red squirrels (*Tamiasciurus hudsonicus*) and deer mice (*Peromyscus maniculatus*) (Schmidt and Shearer 1971). Drought and competition from grasses is a significant problem for seedlings if regeneration, following severe fires or clearcuts, is delayed long

enough for grasses to dominate the site (Schubert 1974).

High temperatures and low moisture limit the number of species that grow together in this zone. One or two major species on any given site is the general rule. Consequently, the choice of species to grow on any given area is very restricted, which in turn limits the silvicultural options. The following sections describe the available silvicultural methods and how they fit the ecological requirements of the various species and combinations of species found in this zone.

Individual Tree and Group Selection--Both individual tree and group selection cutting methods have been used to naturally regenerate ponderosa pine and Douglas-fir (Alexander 1986c). Selection in pinyon-juniper woodlands has also been successful (Bassett 1987). Except on grassy sites the logging process usually results in enough disturbance to provide adequate mineral soil seedbed for seedling establishment.

Continued use of these methods results in many-layered stands composed of all ages. Individual tree selection is most favorable for the shade-loving species and the group selection method is usually favorable to both the shade- and sun-loving species. For example, in a stand with ponderosa pine and Douglas-fir, individual tree selection will result in near pure stands of Douglas-fir while the group selection will accommodate both ponderosa pine and Douglas-fir.

Use of either method has little effect on water yield. Adverse effects on the soil resource are usually minimal. Individual tree selection favors wildlife species, notably small birds, that need multiple canopy layers in the stand, and it is a favored method in streamside areas where shading of streams to maintain cool water temperatures for fish is necessary. Group selection results in more forage production for big game than individual tree selection but overall forage production will generally be low for either method. Seldom can either method be used effectively as a means of increasing forage production for domestic livestock.

If done properly, selection cuttings have the least negative effect on esthetics of any of the silvicultural methods, particularly in the short term and in foreground viewing areas. However, without frequent light underburns or thinnings, neither selection method produces the open grassy stands of big ponderosa pine found most attractive by recreationists.

Selection cuttings generally increase susceptibility to western spruce budworm (*Choristoneura occidentalis*) and Douglas-fir tussock moth (*Orgyia pseudotsugata*) because these methods increase the proportion of the shade-tolerant Douglas-fir and result in multilayered stands--both of which are very favorable for budworm and tussock moth development (Schmidt and others 1983; Carlson and others 1985). Dwarf mistletoe (*Arceuthobium* spp.) severely limits the ability to use selection methods. Selection methods tend to increase the rate and intensity of dwarf mistletoe infection, ultimately leading to deterioration of the stand (Burns 1983).

Risk of fire is higher with uneven- than with even-age methods because of the multilayers in the canopy. The continued presence of small trees in the stand provides the fire ladder into the upper canopy levels (Schubert 1974).

Uneven-aged management requires frequent harvest cuttings. As a result, good access is needed to remove low harvest volumes at periodic intervals. This results in relatively high initial road construction and maintenance costs, particularly on steep slopes--gentle terrain results in lower road costs. On poor sites, both selection cutting methods are difficult to justify economically.

Seed Tree--The seed tree system is an even-aged management system. It has seen little use because natural regeneration has been very difficult to establish in most of this zone. An exception to this is the Black Hills, where natural regeneration of ponderosa pine is more easily established. Cone crop periodicity, competition from grasses, and exposure of seedlings to high surface temperatures appear to contribute to the limited success. Planting is often needed to adequately restock the site with trees. Because the seed tree method has been used so little in this zone it is difficult to generalize how it affects various resource values. However, it can be expected to increase forage for both wildlife and domestic livestock and there is some potential for improving water yields (Burns 1983).

Shelterwood--Shelterwood is an even-aged method widely applicable in these lower elevation forests.

Shelterwoods are commonly used in this zone and are generally successful in regenerating trees naturally because they provide ample seed and partial shade for newly germinated seedlings. The recommended minimum level of reserve trees is 37 to 86/ha (15 to 35/acre)(Burns 1983; Schubert 1974; Boldt and Van Deusen 1974; Bassett 1987). The shelterwood system not only provides seed and shade but also allows some flexibility in adjusting species composition to meet particular management objectives.

Water yields can be improved somewhat and soil disturbance is usually not a significant problem with shelterwoods. Shelterwoods generally favor wildlife species that require large amounts of forage such as big game animals. Forage production under shelterwoods is proportional to the number of trees retained for shelter--the fewer the trees, the greater the forage production. Shelterwoods do not provide as much forage as clearcutting but they can provide some cover value with upper and lower canopy levels for part of the life of the stand. This forest zone often must support wintering populations of big game animals. A major part of the appeal of shelterwood cuttings is that they produce enough timber to make harvest cutting worthwhile, that they produce substantial forage, and that natural regeneration can be used to restock the area without major investments in tree planting (Myers 1974).

Esthetic effects are generally more dramatic immediately after harvesting than those from selection methods. If slash and damaged trees are not removed, a decrease in esthetic values can be expected. Conversely, if cleanup has been well done and understory vegetation response is good, visually attractive stands result (Myers 1974). These values are particularly apparent in ponderosa pine-Douglas-fir forests (Alexander 1986c).

The shelterwood method can effectively treat dwarf mistletoe-infected stands, but the removal cut must be made before the seedlings are infected--usually within 10 years after the initial cutting. If the removal cut is unduly delayed, the understory can be severely infected and the problem is perpetuated.

Overstocked stands of ponderosa pine are susceptible to mountain pine beetle (*Dendroctonus ponderosae*). Trees felled in thinnings or harvest operations can result in a buildup of ips bark beetles (*Ips* spp.) that can damage standing trees (Burns 1983). In much of this zone, overstocking is a frequent problem in newly regenerated stands following shelterwood cuttings. Dense seedling stands are readily killed by high-intensity fires, but fire losses are generally low in stands that have been thinned (Schubert 1974).

Clearcut--As a general rule, clearcutting is not advisable in this zone (Alexander 1986c). High surface temperatures and drought can severely reduce probabilities of obtaining natural regeneration. However, disease, previous cutting practices that have left poor-quality trees, or other factors may make it necessary to clearcut. If so, natural regeneration should not be relied upon because clearcuts can be successfully planted if the site is well prepared and individual tree planting sites are properly selected.

Of all the cutting methods, clearcuts offer the most opportunity for improving water yields, but this lower elevation zone does not provide high yields under any circumstance (Brown and others 1974). Soil erosion is not generally a problem if site preparation and roading are not excessive. Clearcutting results in the maximum forage response for big game and livestock (Patton 1974). In wintering areas for big game, it is important that clearings not be too large and that they be adjacent to stands of trees that can provide visual cover and protection from severe weather conditions in winter (Thomas 1979). In pinyon and juniper stands, large-scale clearings have been used to favor forage for domestic livestock. Many of these clearcuts are regenerated by small advance trees not destroyed during clearing and from seeds of pinyon and juniper carried into the area by birds (Bassett 1987).

Esthetic effects are dramatic and usually adverse in the short term if clearcuts are not carefully planned using principles of landscape design. On good sites, effects are usually short-term because rapidly growing trees soon become established and ameliorate the esthetic impact. On poor sites, the esthetic impacts are longer lasting because of difficulty in establishing small trees and slow rates of growth. Planting poor sites in this zone is often an economic liability because costs occur early in the life of the stand. However, on better sites, ponderosa pine plantations utilizing genetically superior stock are usually economically efficient.

In stands severely infected with dwarf mistletoe, clearcutting is often the only effective method for

treating the stands and preventing the spread of this disease to adjacent, uninfected stands. Prescribed burning is often used in conjunction with clearcutting to improve forage yield, to kill dwarf mistletoe-infected seedlings, and to reduce logging slash. Clearcuts are usually easier to prescribe burn than other regeneration cuts because there are no residual trees to protect.

Lodgepole pine does not occur in this zone except in the Northwest United States. Here lodgepole pine occupies low elevation frost pockets and the cones are largely nonserotinous. Clearcutting can be used to favor natural regeneration of lodgepole pine here, but because of the relatively short seed dispersal distance of lodgepole, large clearcuts do not readily reseed (Lotan and Perry 1983). The relatively short seed dispersal distance of ponderosa pine also limits clearcut width to 152 m (500 ft) or less (Burns 1983).

Thinning--Thinning can be effective in the foothill zone because water is a definite limiting factor in the growth of these forests. Reducing the number of trees makes more water available to the remaining trees which quickly respond by accelerating their diameter growth. Ponderosa pine-Douglas-fir forests are prime examples where thinning can be effective, particularly at younger ages. Very small increases in water yields can be expected, forage for wildlife and domestic stock will generally improve because of increased light and water, and esthetic values will generally improve if thinning slash is properly disposed of. Thinning slash left in place can temporarily increase fire risk but this usually diminishes rapidly, particularly with smaller size trees. Ips beetle attacks are sometimes associated with thinning because they can build their population in fresh thinning slash. To reduce this problem, thinning should be done when the slash will dry rapidly. Also, thinning year after year in the same area should be avoided.

Because much of this zone has limited growth potential, care must be taken in selecting areas to thin. Thinning may be difficult to justify economically on tree growth alone. Tree growth, however, is not the only factor to consider. Increased resistance to insects and disease, better forage and esthetic values, and other noncommodity outputs may well make thinning practical on some areas (Boldt and Van Deusen 1974; Myers 1974). Thinning in Pinyon-Juniper woodlands is seldom economically justifiable unless a high-value product such as Christmas trees can be removed.

Montane Forests

Montane forests are widespread throughout the West, occupying that broad band between the mountain foothills and the subalpine zones. These forests occur in a moderate temperature and moisture belt, usually dictated by elevation. As a result they are diverse in both flora and fauna. The area is often referred to as mixed conifer forests. Interior Douglas-fir is the most commonly found species throughout much of this zone, both geographically and elevationally, but it nearly always grows in association with other conifers. This zone includes all or portions of the types discussed in Agriculture Handbook 445 as follows: Northwest ponderosa pine and associated species; grand fir (*Abies grandis*); Douglas-fir and associated species; ponderosa pine; Rocky Mountain Douglas-fir; western larch (*Larix occidentalis*); lodgepole pine; mixed conifers; western white pine (*Pinus monticola*); western redcedar (*Thuja plicata*); Southwestern mixed conifers; Rocky Mountain aspen (*Populus tremuloides*); and interior ponderosa pine in the Black Hills (Burns 1983). Interior Alaska white spruce (*Picea glauca*) is not a montane type but tends to respond in a similar way.

Major trees that grow in the montane zone are:

Early Successional	Late Successional
Betula papyrifera Paper Birch	*Abies concolor* var. *concolor* White Fir
Larix occidentalis Western Larch	*Abies grandis* Grand Fir
Pinus contorta Lodgepole Pine	*Abies lasiocarpa* Subalpine Fir
Pinus lambertiana Sugar Pine	*Libocedrus decurrens* Incense Cedar
Pinus monticola Western White Pine	*Picea engelmannii* Engelmann Spruce
Pinus ponderosa Ponderosa Pine	*Picea glauca* White Spruce
Pinus strobiformis Southwestern White Pine	*Picea pungens* Blue Spruce
Populus balsamifera Balsam Poplar	*Pseudotsuga menziesii* var. *glauca* Douglas-fir (on some ecological habitats
Populus tremuloides Aspen	*Thuja plicata* Western Redcedar
Pseudotsuga menziesii var. *glauca* Douglas-fir (on some ecological habitats)	*Tsuga heterophylla* Western Hemlock

Fire has done much to shape the character of the stands and the trees that occupy this zone. As a result, understanding fire ecology is particularly crucial in determining appropriate silviculture (Gruell and others 1982). Fires are frequent but less so than in the drier-warmer foothills zone where ponderosa pine and Douglas-fir predominate. Stands here tend to be more productive and contain more natural fuels. When fires do occur, they typically destroy almost all trees in a stand (Burns 1983; Jones 1974).

To adapt to this situation, two groups of species developed over time. There is a group of plant and animal species (early successional) that benefits from frequent fire. Fire-adapted trees tend to invade openings rapidly, grow rapidly in height, and demand full exposure to sunlight. Western larch, lodgepole pine, aspen, and western white pine fit this category--they depend on fires or other disturbances to regenerate. In this zone ponderosa pine and, to a lesser extent, Douglas-fir are also favored by fire and major disturbances. Deer (*Odocoileus* spp.) and elk (*Cervus* spp.) are two wildlife species that benefit by the forage conditions stimulated by fire (Burns 1983; Thomas 1979).

A second group of species (late successional) are favored by long intervals between fires or major disturbances. These species are adapted to growing in the shade of other trees and are very fire susceptible because of highly flammable crowns and thin bark, which provides little insulation for the heat-sensitive cambial layer inside the bark. They typically invade

the early successional stands of trees that were established soon after a fire and eventually replace them. Tree species that are favored by lack of fire or other disturbances include white fir, grand fir, western redcedar, and white spruce. Wildlife species found in late succession stands often include cavity nesting birds such as woodpeckers and species favored by multiple canopy levels (Thomas 1979).

Like in the foothills zone, both long-term fire protection and harvesting have had major effects on montane forests. Prior to settlement in the late 1800's and early 1900's, fire frequencies were likely in the range of 20 to 40 years (Arno and Gruell 1987). This restricted succession and resulted in stands composed largely of early successional species. For much of this century effective fire protection has allowed many stands to move further toward stands comprised primarily of late successional and climax species. Over much of the West for most of this century, various forms of cutting that favored late successional species and discriminated against early successional species were the favored methods of harvesting. These two practices--fire protection and selection cutting--accelerated the succession toward stands comprised largely of shade-tolerant species such as white fir, grand fir, and Douglas-fir. In the northern Rockies, there has been more use of clearcutting for the past three or four decades and the succession toward shade-tolerant species may be less pronounced than in the southern Rockies.

Annual productivity of sites in the montane is substantially higher than for those in the lower slopes and foothills zone, but the variation is large, ranging from less than 3.5 to more than 8.4 m^3/ha (50 to more than 120 ft^3/acre). Economic values also range widely, depending on the species and local market situation, but merchantable timber volumes are generally higher for harvest cuts than in either the foothills or subalpine zone (Burns 1983).

Insects and diseases are a significant management problem in this zone but they vary substantially depending on local situations. Dwarf mistletoe is a serious problem in Douglas-fir, western larch, lodgepole pine, and in some areas of ponderosa pine (Drummond 1982). In areas where grand fir, white fir, blue spruce, or Douglas-fir are late successional species, western spruce budworm is a current and increasing problem. Also, Douglas-fir tussock moth is a periodic defoliator of Douglas-fir, white fir, and grand fir. Douglas-fir bark beetle (*Dendroctonus pseudotsugae*) can be a serious mortality factor of old-growth Douglas-fir in some locations. Mountain pine beetle causes recurring losses in lodgepole pine forests and is a significant management problem over a wide range of ecological habitats, in many cases essentially dictating management direction (McGregor and Cole 1985; Alexander 1986a). Root rots (*Armillaria mellea* and *Phellinus weirii*) are serious problems in localized areas killing most species of trees near infection centers. Various stem rots and decays also cause defects in all species. Indian paint fungus (*Echinodontium tinctorum* is a major cause of defect in grand fir and white fir.

The susceptibility and vulnerability of these forests to nearly all insect and disease problems are related to tree, stand, and site conditions such as age, stand density and structure, elevation, aspect, and the like. Most tree and stand conditions can be manipulated to reduce insect and disease problems. Silvicultural treatments can be particularly effective against western spruce budworm, Douglas-fir tussock moth, the various beetles, and dwarf mistletoe. This is not to imply that answers are available to solve all insect, disease, and animal problems, but substantial headway has been made. Important problems still exist, particularly with some of the diseases, cone insects, bear damage in young larch stands (Schmidt and others 1976), and pocket gophers' (*Thomomys* spp.) extensive damage to planted trees (Jones 1974).

As a general rule, seed supplies from healthy stands are usually adequate for natural regeneration in this zone, but harvesting and site preparation need to be coordinated with prospective cone crops to be most effective (Burns 1983). Seed production for most of the species in this zone varies substantially from year to year. On a long-term basis, a 5-year period usually includes one heavy crop, two moderate crops, and two near-failures. All seed crops are strongly affected by factors such as unseasonable frosts, insects, and animals such as squirrels. Seed dispersal distances vary considerably by species with western hemlock one of the longest and lodgepole pine one of the shortest in dispersal distances (McCaughey and others 1986). The absence of current seed crops or the need to establish genetically improved growing stock sometimes necessitates planting. Nearly all species in this zone are well adapted to planting.

Much of the montane zone occurs on steep mountain topography. Exceptions to this are the extensive lodgepole pine forests of the Rockies and the spruce forests of interior Alaska, both of which occur mostly on relatively gentle terrain (Baumgartner and others 1985). Logging technology for steep slopes has advanced substantially, but it is still difficult to apply efficiently with selection cuttings. Consequently harvesting costs are usually high.

A unique species in this complex is western redcedar. It is subject to fewer economic limitations than the other late seral species because good markets exist for trees of all sizes and even for large trees affected by decay.

The large number of species in the Montane zone--ranging from 2 or 3 on some sites up to 10 on others--makes possible a broad array of silvicultural options. The following sections describe some of the options.

Individual Tree and Group Selection--Selection methods strongly favor late successional species that can tolerate shade during both the regeneration and subsequent growth stages. Individual tree selection particularly favors shade-tolerant species because the openings created by individual tree removals are so small that little sunlight is available for seedlings that regenerate in the openings. As a result, true firs such as grand fir, white fir, subalpine fir and the other shade tolerants such as western hemlock and western redcedar will usually occupy most of the sites where repeated individual tree selection is practiced. This is at the expense of the early successional species.

Group selection offers a better chance of maintaining more early successional species in the stand, but neither individual tree or group selection methods are very reliable in this respect (Burns 1983). Because of frequent logging entries needed to accommodate selection cuttings and relatively low volumes removed in each entry, economic efficiency is often a concern. Some of the favored late successional species (grand fir, white fir, western hemlock, and subalpine fir) are of lesser value than early successional species, are easily damaged by logging, and decay rapidly once injured (Gottfried and Jones 1975; Aho and others 1983). Good road access is needed to meet the frequent harvest entries necessary for uneven-aged management.

Water yield increases are low for selection methods because most of the water-demanding trees are still on the site after harvesting. Effects on soil loss and water quality are minimal. For these reasons, stream-side areas are often managed by means of individual tree selection (Graham and Smith 1983).

Selection methods favor wildlife species that require multilayered canopies, notably bird species. Also, stands managed with selection cuttings often provide good cover for big game species, but increases in forage after cutting are usually minimal for either wildlife or domestic livestock (Thomas 1979).

Areas where esthetic values predominate, and where sudden changes in forest conditions are visually undesirable, are often best managed with selection methods. Conversely, stands of aspen or western larch, which provide fall color and visual contrast year around, cannot be maintained with individual tree selection, but group selection cutting methods offer some opportunities in parts of this zone (Burns 1983).

In areas where white fir, grand fir, Douglas-fir, or blue spruce are the late successional trees, selection methods encourage a buildup of western spruce budworm populations because they create the conditions most needed by the budworm--a multilayered stand composed primarily of host species (Schmidt and others 1983; Carlson and others 1985). If root rots are severe, selection methods are not usually successful (Burns 1983).

Effects of selection cutting on dwarf mistletoe are variable. If the trees in the stand affected are early successional, selection will usually cause the infection to intensify (Jones 1974).

Prescribed burning is impractical with selection cutting because of the presence of many small trees and species that are easily killed by fire. Risk of fire loss is higher than for even-aged stands because ground fires can easily spread up through the many-layered canopy. Thorough disposal of logging slash is usually not possible without unacceptable damage to the stand (Jones 1974).

Seed Tree--The seed tree method can be used successfully in the montane zone. It is particularly appropriate in naturally regenerating some of the early successional trees, most notably western larch, but also ponderosa pine, Douglas-fir, and western

white pine. Because aspen reproduces by sprouting and much of the lodgepole pine in this zone retains its seeds in serotinous cones and is not windfirm, the seed tree method is not effective or needed for these species (Burns 1983).

Late successional species are not well adapted to the seed tree method. Blowdown, breakage, and sunscald of the seed trees is common. Also, exposed site conditions often cause heat or frost damage to the newly germinated seedlings of shade-tolerant trees such as grand fir, white fir, and subalpine fir (Burns 1983).

The seed tree method affects resource values in much the same manner as clearcutting and will be discussed in that section.

Shelterwood--The shelterwood system is broadly applicable in the montane zone. It can be used to favor both early successional trees and many of the late successional trees. Early successional species are favored by heavier removals that retain as few as 37 trees/ha (15/acre). If available, a good representation of early successional trees should be retained in the reserve shelterwoods because they generally are faster growing and are also better able to resist damage from exposure to wind and sun. With heavy cuts, the shelterwood method can favor ponderosa pine, western larch, Douglas-fir, western white pine, and southwestern white pine or sugar pine if seed sources are present. Planting is sometimes necessary to establish ponderosa pine and Douglas-fir (Seidel and Head 1983). If a substantial degree of shelter with as many as 99 trees/ha (40/acre) is left with a seed source of late successional trees, late successional seedlings will tend to predominate in the newly regenerated stand. At the same time, risk of losses in the overstory is minimized.

Water yield can be increased moderately by shelterwood cuttings, with more water produced by the heavier cuts. Effects on soils and water quality are usually well within acceptable limits (Rich and Thompson 1974).

Forage for wildlife species can be increased but not to the extent that it can with clearcuts. There is limited potential for having two canopy levels favorable to some bird species for part of the life of the stand. The method has the potential of producing a mosaic of stand conditions important for habitat diversity (Thomas 1979). Some important early successional tree species such as aspen, western larch, ponderosa pine, and lodgepole pine regenerate satisfactorily but their seedling development is inhibited substantially if the overwood is retained too long (Burns 1983).

An important consideration in managing for habitat and ecological diversity in this zone is the fact that most stands of early successional tree species will have been invaded by seedlings of late successional species before they mature. In many cases, it is economically attractive to retain these "advance" seedlings and not incur a reforestation cost or adverse visual effect. Substantial areas in all geographic regions of the montane zone have been converted to later successional stages with this sometimes controversial practice. The above advantages are generally at the expense of fewer numbers of much faster growing, early successional species and the creation of stands composed largely of shade-tolerant species that are far more susceptible to insects, such as budworm and tussock moth, and diseases.

Root rots can be a complicating factor that reduce chances for success of shelterwood, especially if the available trees for seed and shelter are highly susceptible species such as Douglas-fir or grand fir (Burns 1983; Jones 1974). Livestock forage, particularly for one or two decades, may be improved with the shelterwood method. This may be locally important. The heaviest cuts tend to produce the most forage.

Esthetic effects are usually somewhere between those achieved by selection and clearcutting. If slash is disposed of and damaged trees removed, adverse visual effects are minimized, especially if good-quality trees are retained as the shelterwood.

Prescribed burning is practical in shelterwood cuts if the trees retained for shelter are resistant to fire damage (Petersen and Mohr 1984). In this zone, Douglas-fir, ponderosa pine, and western larch can withstand the burning intensities commonly prescribed. Other species are readily killed by fires. Burning is a good technique for eliminating preexisting regeneration of late successional species before seedlings of the early successional species get started.

With the shelterwood method, overstocking is a common problem. Thinning, as described later, is often needed both to reduce competition between

the small trees and to increase the proportion of early successional species in the stand.

Clearcut--Clearcutting has broad applicability in this zone. It most nearly matches the role formerly played by forest fires. It is often considered the optimum method for regenerating aspen, lodgepole pine with serotinous cones, western larch, mixed conifers in the western white pine type, and others. It is also the most effective method for treating stands heavily infected with dwarf mistletoe and root rots. It is often the only practical method to use in stands of late successional species that have deteriorated to the point where there is an insufficient number of good trees for selection or shelterwood methods to be effective (Burns 1983; Jones 1974).

Planting of desired species is sometimes needed to ensure prompt regeneration and to avoid excessive competition with many fast-growing shrub species that are also favored by this method. This zone is the most productive area of the inland West and the clearcut method enables genetically improved planting stock of several species to capitalize on this site productivity.

Clearcutting can significantly increase water yields (Alexander 1986a). If clearings are too extensive over a short time period in a specific watershed, increases in water yields can damage stream channels. Hydrologic limits, specific to the area, should be set for watersheds to reduce the potential for excessive increases in water yield. The clearcutting method does not usually change water quality or result in soil damage (Rich and Thompson 1974). However, there are areas of unstable or erosive soils in this zone that call for limitations on clearcutting. Clearcutting is not a preferred method of cutting in streamside zones, especially where shading of streams is desired to maintain cool water temperatures (Burns 1983).

Clearcutting usually favors wildlife species such as elk, deer, moose (*Alces alces*), and hares (*Lepus americanus*) that capitalize on the increased forage, particularly if it is in the proximity of adequate cover (Alexander 1986a). It does not favor species that require multicanopy levels such as cavity nesting birds unless long rotation ages are used and some effort is made to retain snags. Clearcuttings done at periodic intervals in an area help perpetuate a diverse mosaic of habitat conditions (Thomas 1979). Forage for domestic livestock can be substantially increased with clearcutting, and this can be locally important. However, it is usually best to delay grazing for several years until the young seedlings have become well established and are less susceptible to trampling and foraging by domestic stock. Substantial areas within the zone, particularly on steep slopes, have not been important for livestock grazing.

Thinning--Thinning is practiced widely in the montane zone and justifiably so. Sites in this zone are usually regenerated with so many trees that none of them have adequate room to grow close to their potential. Also, the wide variety of species available on many montane sites, the good growth potential of many of them, and the opportunity to increase associated resource values provide much impetus for thinning.

Water, light, and nutrients can all be limiting factors for growth in this zone. Thinning makes more of each factor available to the reserved trees. As a result, nearly all studies show thinning markedly increases diameter growth, particularly in younger stands. As a rule of thumb, thinnings are most effective when stands are in the range of 15 to 30 years old. By this time natural succession has reduced some of the early overstocking, but the individual trees still have adequate crowns to capitalize on increased growing space following thinning.

Because early successional species such as western larch, lodgepole pine, western white pine, and ponderosa pine generally have the greatest growth potential in the younger ages, stands with large components of these species are generally the best candidates for early thinning. As a general rule, species diversity should be maintained by retaining as many species with good growth potential as possible in the reserve stand.

Thinning will not only enhance growth but it can also reduce susceptibility to insects such as budworm and bark beetles (*Dendroctonus* spp.), increase water yields and forage production, and improve esthetics. Conversely, thinning slash is usually heavy in this zone and it can inhibit wildlife movement. Slash improperly cared for may reduce esthetic values and temporarily increase fire risks. Also, if too few trees are reserved, visual and thermal cover may be inadequate for wildlife.

Thinning usually requires some initial investment but the growth potential and the opportunity of reducing

insect and disease problems and enhancing associated resource values generally will justify the costs.

Subalpine Forests

Subalpine forests abut the alpine zone and occupy the coldest and generally wettest zone of the inland mountain West. Characterized by short growing seasons and deep snow, these areas are usually dominated by the spirelike forms of Engelmann spruce and subalpine fir (Alexander 1986b). Relatively few tree species are capable of growing on these subalpine sites and although these high-elevation areas are less productive than the montane zone below them, they are still very important for timber, esthetics and recreation, summer forage for wildlife and domestic stock, and particularly for water.

This zone includes all or portions of the following cover types: engelmann spruce-subalpine fir, lodgepole pine, and aspen.

Tree species include:

Abies lasiocarpa
Subalpine Fir

Abies lasiocarpa var. *arizonica*
Corkbark Fir

Larix lyallii
Subalpine Larch

Pinus albicaulis
Whitebark Pine

Pinus aristata
Bristlecone Pine

Pinus contorta
Lodgepole Pine

Picea engelmannii
Engelmann Spruce

Populus tremuloides
Aspen

Tsuga mertensiana
Mountain Hemlock

The primary commercial species in this zone are Engelmann spruce and lodgepole pine. Other species, such as subalpine fir and mountain hemlock, are harvested but often have less value or are infected with trunk rot. Productivity of sites in this zone varies substantially, ranging from less than 1.4 to more than 6.0 m^3/ha (less than 20 to more than 85 ft^3/acre) per year. Very severe sites within the zone are often marked with scattered occurence of species such as bristlecone pine, whitebark pine, subalpine larch, and tundralike plants in the understory. All of the latter species contribute substantially to the uniqueness and esthetic values of this zone. Whitebark pine is particularly important because it produces cones and seeds that are key items in the diet of the grizzly bear (*Ursus arctos horribilis*), particularly important in the Yellowstone ecosystem.

Natural fires in this zone are less frequent than in either the montane or foothills zones, and their intervals are less well documented. When fires do occur, they are generally conflagrations in which all trees in the stand are killed. In the lower part of this zone, lodgepole pine and aspen often invade burned stands in a fashion similar to the montane zone. At the higher elevations, it is too cold for lodgepole pine or aspen and burned areas tend to be reinvaded very slowly by subalpine fir and Engelmann spruce or by mountain hemlock (*Tsuga mertensiana*) in the Northwest (Alexander 1974; Burns 1983).

In the early days, the alpine zone above timberline was important summer grazing for both sheep and cattle. Since then, grazing has gradually decreased in importance, but it remains a significant resource at certain locations throughout the upper subalpine and alpine zone.

Timber harvesting has long been important locally beginning in areas with long mining histories but more generally from the 1950's to the present. Extensive outbreaks of spruce bark beetles (*Dendroctonus rufipennis*) in the 1950's were the impetus for much of the cutting in the next two decades. Timber harvest is still a major activity in portions of the subalpine zone.

harvest is still a major activity in portions of the subalpine zone.

Throughout the subalpine zone, recreation use has increased substantially, especially since the 1960's. Substantial portions of this zone occur in wilderness, parks, and other areas dedicated primarily to recreation. Wilderness, backcountry hiking, cross-country skiing, downhill skiing, and snowmobiling have become very important in parts of the zone. Management of forests to protect the esthetics or for snow retention in high-use recreational areas is becoming increasingly important. Because of the slow-melting deep snows accumulated in the winter months, this zone is the primary contributor to streamflow during the dry summer period. Fisheries, irrigation, and municipal water uses depend heavily on water flowing from this zone (Burns 1983; Alexander 1986b).

Trees that grow here are well adapted to the short growing season and cold-moist conditions and generally produce good seed crops at regular intervals. Deep snow often causes problems for seedlings and saplings, which tend to be very slow growing. Snow mold (*Neopeckia coulteri*), frost damage, high light intensity, and snow bending of young trees are important problems in this zone (Dobbs 1972). Large trees tend to be shallow rooted and subject to windthrow when stands are disturbed (Alexander 1974; Burns 1983).

Species options are fewer and site conditions more restricted in this zone than in the montane. These restrictions are somewhat offset by fewer insect and disease problems so common in the lower elevation areas. For example, budworm may feed occasionally on the true firs and spruce in this zone but the climate is apparently severe and erratic enough to limit sustained budworm populations.

Much the same situation exists for mountain pine beetle in this zone. Epidemic populations of beetles that have built up in lower elevation forests sometimes move upward into this zone, causing significant mortality of lodgepole pine and occasionally whitebark pine. However, high populations of the beetle are seldom sustained in this zone.

The most significant insect problem is the spruce bark beetle. Extensive stands of mature spruce can be decimated by the spruce bark beetle. Infestations of the beetle are usually triggered by blowdowns, providing ample food for population buildup and spread to standing timber.

The following sections describe some of the advantages and disadvantages of the various silvicultural options in the subalpine zone.

Individual Tree Selection and Group Selection--Both uneven-aged methods have been used to successfully regenerate Engelmann spruce and subalpine fir (Alexander 1986b). Individual tree selection is a suitable treatment on some sites and, because of subalpine fir's prolific seeding and extreme tolerance of shade, tends to favor subalpine fir over Engelmann spruce. Its use can also be expected to favor mountain hemlock where it occurs. Small group selection cuts are usually more practical because they are more easily adapted to stands that are of a patchy nature, and harvesting and site preparation, if needed, are more easily accomplished.

Several things stand out with respect to natural regeneration following cutting. Reaching full stocking with natural regeneration is a slow gradual process on most spruce-fir sites (Fiedler and others 1985). Shade is an important component in seedling establishment. Initial seedling growth, particularly under the overwood, is very slow. Both spruce and fir grow slowly in the subalpine zone but will respond with increased growth when released by partial or total removal of the overwood (McCaughey and Schmidt 1982).

Selection cuttings have the least effect on water yield of any of the silvicultural systems in this high water yielding zone. Use of either of the selection methods requires an extensive road system and relatively frequent timber harvests, both of which can impact the soil resource. However, adverse effects are usually minimal. Water temperatures are less of a problem in this zone but, even so, stream side zones are usually left intact or selectively cut. This forest cover provides cool shade for the stream and protects the streambanks from disturbance.

Wildlife dependent upon multiple canopy levels in the stand are benefited by selection cutting, but forage production is very low. High recreational use and associated concern for esthetics are often reasons for choosing individual tree selection over other methods.

Light selection cuts are less susceptible to blowdown than heavier cuts. Where windthrow risk is severe, such as in saddles, even selection is not adequate and the choices are no cut or clearcut. Because western spruce budworm is not very active in this high-elevation zone, choice of cutting method need be little influenced by budworm. However, spruce bark beetles are a constant threat in mature forests. Rapid removal of blowdown and harvesting of beetle-susceptible mature timber will usually limit beetle infestations.

Frequent cutting entries needed to effectively conduct uneven-aged management require a good road network, which results in fairly high development costs in these sometimes fragile areas. Also, rapid infection by decay in residual trees damaged by logging detracts from application of the method (Hinds and others 1983). Low volumes and values are economic limitations on the use of selection methods.

Prescribed fire can damage stands in this zone, especially in stands managed by selection. When it is dry enough for wildfires to burn well, none of the silvicultural methods offer much protection to these fire-sensitive species.

Seed Tree--Because of the shallow-rooted nature of trees in this zone, the risk of blowdown of seed trees all but precludes use of the seed tree method.

Shelterwood--The shelterwood method is widely applicable in this zone. It has generally been used successfully in naturally regenerating both Engelmann spruce and subalpine fir as well as mountain hemlock. Because of the risk of blowdown, a three-step shelterwood is often best but a two-step shelterwood is a good method in sheltered locations. In this zone, the minimum shelterwood should retain about 62 trees/ha (25/acre) after the seed cut with a high proportion of Engelmann spruce or mountain hemlock. This is because their common associates, subalpine or corkbark fir, are more easily damaged by exposure. Also, if possible, a fairly heavy seed source of the more valuable spruce should be retained (Alexander 1974).

Water yields can be increased using shelterwood methods in this water-rich zone. Shelterwood effects on soils and water quality are intermediate between selection and clearcutting.

Wildlife and domestic livestock forage can be improved to a limited extent but the need to retain more overstory than in other zones tends to suppress understory growth. Shade also tends to perpetuate some shrubby plants rather than grasses and sedges that prefer more open conditions.

Shelterwoods also have advantages in regenerating trees because the overwood provides shade from the intense light at this elevation, tends to reduce frost damage to seedlings, and also helps prevent snow bending due to downhill creeping of the snowpack. Because of this, shelterwoods help reduce or eliminate the amount of planting so often needed with clearcutting, an important item in an area where timber value is relatively low (Alexander 1974).

Esthetic effects of shelterwoods are intermediate between selection and clearcutting. If cleanup of logging slash is good, visual effects are not dramatic. Disposal of the slash material can be difficult and both an economic and biological problem. Prescribed burning is difficult under a shelterwood in the subalpine zone because it can easily damage the residual stands, which are very sensitive to fire. If stands are accessible to the public, the material can often be removed as fuelwood.

In this zone, overstocking is far less of a problem than in the montane zone, but the shelterwood method sometimes produces heavily stocked young stands that later need thinning.

Clearcut--Clearcuts can be used successfully in these subalpine forests (Alexander 1986b). Natural regeneration of spruce, fir, and mountain hemlock can be achieved if the site is prepared to expose mineral soil in well distributed spots, if dead shade in the form of debris is well-distributed, and if these are coordinated with adequate seed dispersal. This usually means that the size of opening must be kept to less than 5 or 6 times the height of the adjacent seed source. Centers of openings larger than this will generally receive inadequate seed and will require planting as soon as possible to avoid competition of rapidly invading grasses and sedges that thrive in these openings.

Excessive cleanup of logging slash and overly large clearcuts cause an exposed environment in which it is very difficult for small seedlings to survive. High-intensity winds, the intense sunshine of high elevations, and frost need to be partially blocked by keeping

the openings small and providing some logs or slash for sheltering seedlings until they are established. Prescribed burning is often detrimental to seedling establishment in this zone because it creates too harsh an environment. Also, if incorrectly timed, fires will kill seedlings that may have been in the stand before logging. The presence of this advance regeneration is often helpful in establishing a new stand (Alexander 1974).

Lodgepole pine and aspen fare well in clearcuts at lower elevations in the subalpine zone and are able to regenerate in larger openings because of serotinous cones and sprouting ability, respectively (Burns 1983).

Where blowdown risk is very high, such as in saddles where winds are funneled, either clearcutting or no harvesting at all is the only viable silvicultural option. Clearcuts are also an option where bark beetles or other mortality have so reduced the number of good trees that other methods are impractical.

Clearcutting is the optimum method for increasing water yield if the openings are moderate in size and well spaced (Leaf 1975). Deep snowpacks accumulated in clearcuts tend to melt later in the summer, maintaining better streamflow in the dry months. Loss of soil and water quality is almost always within acceptable limits if reasonable care is taken in logging and road construction.

Clearcutting, more than any other cutting method, maximizes forage production for domestic livestock and wildlife summer range. However, if the objective is to regenerate a clearcut with trees, livestock grazing may have to be delayed until the new tree seedlings are well established. This is particularly so on the gentle terrain favored by livestock on high plateaus. To favor wildlife use, openings should be relatively small to provide nearby cover for foraging animals such as deer, elk, and moose. Blue grouse (*Dendragus obscurus*) also tend to favor openings in the subalpine zone.

Esthetics can be adversely affected by clearcuts in these highly visible areas, and landscaping principles should be followed closely in designing clearcuts. Because of slow seedling growth, clearcuts often persist visually for 20 years or more. Where dead trees from bark beetles are not salvageable and where large amounts of dead material are left on the ground after logging, esthetic values decline. These areas usually need cleanup to improve esthetic values, but the need for seedling shade provided by the debris usually means making compromises in the level of cleanup.

Stands at timberline on dry, wind-swept ridges or on other severe sites should not be clearcut if regeneration of tree stands is expected. Large openings that require tree planting are not likely to be economically, biologically, or socially acceptable and should be avoided.

Thinning--There has been little thinning in the subalpine zone because the opportunities are fewer and the need less pronounced than in the montane zone below. Water is less limiting in this zone than at lower elevations and increasing available water is generally the primary impetus for thinning. However, adjusting species composition and providing additional room to grow for featured trees and improving wildlife and esthetic values justify the use of thinning on some sites in this zone. If done too radically, windthrow and snow breakage can be a problem here.

Summary

Silviculture for the western inland conifers must:

1. Be in tune with land management objectives.
2. Be compatible with ecological requirements of the individual species as well as the entire plant and animal community.
3. Take insect, disease, and animal problems into consideration.
4. Maintain or improve site productivity.
5. Maintain diversity of plant and animal life.
6. Evaluate alternatives that can be used to enhance the various resources including timber, water, recreation, esthetics, forage, and cover for wildlife and domestic livestock.
7. Be realistic in terms of economic, social, and biological goals.

The inland West is a broad geographic area that we have divided into three zones: the foothills, the montane, and the subalpine. Even with this division, there is tremendous variation in each of the zones and only broad silvicultural guidelines are presented here. In reality, silviculture prescriptions must be made on a stand-by-stand basis and must integrate stand conditions, site potentials, species requirements, economics, and management objectives.

Our western inland forests are both storehouses of valuable forest resources and natural factories capable of producing a continual flow of these resources into the future. How we choose to manage these forests to meet social and economic goals and realities must be based on sound ecological principles. Proper management ensures the perpetuation of these valuable forest resources.

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Silviculture of Pacific Coast Forests

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Extent and Location of Pacific Coast Forests

Pacific coast forests occupy about 28.3 million hectares (70 million acres) of commercial forest land in south central and southeastern Alaska and in Washington, Oregon, and California west of the crests of the Cascade and Sierra Nevada Mountains (USDA Forest Service 1982). These forests cover about one-seventh of the total commercial forest land in the entire country. The national forests have about 13 million hectares (32 million acres) of Pacific coast forests, which is about 35 percent of the total commercial forest land in the entire National Forest System. However, the potential total wood production of Pacific coast forests is about 50 percent of the potential for all commercial forest lands in the National Forest System (USDA Forest Service 1984).

The Society of American Foresters has classified 28 forest types in the Pacific coast forests, indicating the great ecological and geographic diversity occurring there (Eyre 1980). The 28 types occur in different environments, usually caused by the different temperature and moisture conditions associated with coastal, inland, or mountainous conditions. For convenience in this discussion, the 28 types have been combined into six major kinds of forests.

Western hemlock-Sitka spruce forests are northern coastal forests dominated by western hemlock (*Tsuga heterophylla*) and Sitka spruce (*Picea sitchensis*), occurring in areas with a maritime climate from south-central Alaska to southern Oregon. Associated coniferous and hardwood species include Douglas-fir (*Pseudotsuga menziesii*), western redcedar (*Thuja plicata*), Alaska-cedar (*Chamaecyparis nootkatensis*), red alder (*Alnus rubra*), vine maple (*Acer circinatum*), and bigleaf maple (*A. macrophyllum*) (Minore 1980). Hardwood-dominated stands are a minor component of these forests.

Douglas-fir forests are widely distributed inland from the hemlock-spruce forests, at low elevations west of the Cascade Range in Washington and Oregon, and on the west side of the Coast Range in northwestern California. The environments are characterized by moderate temperatures and soil moisture conditions. Associated conifers and hardwoods include western hemlock, western redcedar, red alder, black cottonwood (*Populus trichocarpa*), bigleaf maple, vine maple, tanoak (*Lithocarpus densiflorus*), and Pacific madrone (*Arbutus menziesii*) (Williamson 1980).

True fir-hemlock forests occur on the middle and upper slopes of the Cascade Range in Washington, Oregon, and California; in the Olympic Mountains of Washington; and on the upper slopes of the Sierra Nevada and northern Coast Ranges in California. The climate is cool and wet; snowpacks are present up to 8 months each year. The common dominant conifer species vary by latitude and elevation, occurring singly or in different associations: Pacific silver fir (*Abies amabilis*), mountain hemlock (*Tsuga mertensiana*), noble fir (*Abies procera*), California red fir (*A. magnifica*), grand fir (*A. grandis*), white fir (*A. concolor*), western redcedar, Alaska-cedar, and western white pine (*Pinus monticola*) (Franklin 1980a, 1980b, Gordon 1980).

Hardwood forests occur at low to middle elevations from Alaska to southern California. These forests are not extensive in the Pacific Northwest but cover millions of hectares (acres) around California's Central Valley and southern Coast Range. The species composition also varies greatly with latitude. Red alder and black cottonwood stands dominate in the cool, moist northern environments. Tanoak and Pacific madrone occur in the somewhat drier and warmer environments of southwestern Oregon and northern California. Farther south, coast live oak (*Quercus agrifolia*) woodlands are sometimes associated with California-laurel (*Umbellularia californica*) near the coast. Inland central and southern California woodland associates include canyon live oak (*Quercus chrysolepis*), valley oak (*Q. lobata*), and blue oak (*Q. douglasii*) (Finch and McCleery 1980).

Redwood forests typically occur on moist river flats and cool slopes near the coast up to about 915 m (3,000 ft) elevation in northwest and central California, and in the extreme southwestern corner of Oregon (Roy 1980). Common associates of redwood (*Sequoia sempervirens*) are Douglas-fir, Port-Orford-cedar (*Chamaecyparis lawsoniana*), tanoak, Pacific madrone, and California-laurel.

Mixed conifer forests occur on drier sites inland from the Douglas-fir forests and at lower elevations than the true fir-hemlock forests in southwestern Oregon and northern California. The range extends south along the Sierra Nevada Range to the Transverse Ranges of southern California. Stands typically consist of Douglas-fir, ponderosa pine (*Pinus ponderosa*), sugar pine (*P. lambertiana*), white fir, and incense-cedar (*Librocedrus decurrens*), but composition varies considerably. Common associates are Oregon white oak *Quercus garryana*), California black oak (*Q. kelloggii*), and canyon live oak (McDonald 1980, Sawyer 1980, Tappeiner 1980).

Ecological and Historical Overview

Along the Pacific coast of North America lie some of the most valuable and complex forests in the world. Many of the tree species have commercial timber values, and are unsurpassed in their size and longevity. In addition, there are hundreds of species of shrubs and other plants. The forests contain highly valuable watersheds, and they provide significant range and recreation resources as well as prime habitat for wildlife and fish.

The various tree species have different traits that enable them to become established, grow, and reproduce under specific forest environments. Such adaptations may influence the kinds of cutting practices appropriate for each species and forest types.

Adaptations to Scale of Forest Disturbance

Some species, such as western hemlock, white fir, and tanoak, are adapted for establishment and growth in small openings caused by minor disturbances, such as the death or harvesting of a single large tree. These species are generally characterized by tolerance of shade. Also, the seedlings of these species often become established in soils with a litter layer of dead and decaying leaves and branch fragments; a bare soil seedbed is not needed (Williamson 1976, Laacke and Fiske 1983a, McDonald 1978).

In contrast, other species are well adapted to large openings, created by wildfire, extensive windthrow, flooding, timber cutting, or agricultural cultivation. Such species are referred to as "pioneers" and include some of the most sought-after timber trees: Douglas-fir, ponderosa pine, redwood, and sugar pine. These species can become established and grow rapidly in conditions of bare soil, full sunlight, and wide temperature fluctuations associated with large forest openings.

Between the extremes are many other species that are well adapted to openings of intermediate sizes or to disturbances of moderate severity. Moreover, many species are able to complete their life cycles in openings of various sizes.

Fire Adaptations

Most Pacific coast tree species have adaptations to cope with periodic wildfires. Redwood, tanoak, Pacific madrone, and the live oaks sprout vigorously from root crowns or the base of the trunk, even after being severely burned. Many hardwood seedlings or saplings develop root burls so that they can sprout after fires. Other species develop thick bark to insulate against heat injury, such as ponderosa pine, sugar pine, redwood, and giant sequoia (*Sequoiadendron giganteum*). Some species, such as lodgepole pine

(*Pinus contorta*), Monterey pine (*P. radiata*), and knobcone pine (*P. attenuata*), take advantage of wildfire-created openings by having cones that stay closed until heated. Douglas-fir, hemlock, and white fir can disperse their seed via wind over considerable distances to burned-over areas.

Adaptations for Inter-plant Competition

Because of the wide variety of environments and kinds of plants in the Pacific coast forests, adaptations for inter-plant competition vary considerably. The capacity of seedlings to become established and grow rapidly is limited primarily by competition with other plants for light in moist coastal environments and for soil moisture in the drier inland environments. Successful establishment on inland sites depends on the species' capacity to rapidly develop deep and extensive root systems. Pioneer trees, such as Douglas-fir and ponderosa pine, depend on rapid early shoot growth to compete successfully for light. Shade-tolerant species, such as white fir and tanoak, can endure slow shoot growth for decades, yet they respond rapidly when exposed to additional sunlight associated with new openings, or after their crowns grow above the competing vegetation (Laacke and Fiske 1983a, McDonald and others 1983).

Origins of Present Forests

Most Pacific coast forests originated following major land disturbances. In coastal Alaska, glacial advance and retreat has been and continues to be a significant factor in establishment of forests. In Washington, Oregon, and California, however, most of today's old-growth forests were established following fires occurring centuries ago. Many of today's young-growth forests typically were established after fires and timber harvesting since the 1830's. Initially, the forests that became the present old-growth and young-growth forests were even aged or nearly so, with the relatively simple structure and species composition associated with stands of pioneer tree species. Where disturbances, such as periodic fires, have been frequent, the even-aged character and dominance of the pioneer tree species has been sustained. In some stands these trees occur in two or three age classes; the origin of each age class followed a fire or other major disturbance, such as a windstorm or tree harvest.

Where frequent major disturbances have not occurred, tree species that are not dependent on major disturbances for establishment, such as western hemlock, some true firs, and tanoak, have become established under the canopies of the pioneer species, thereby creating multiaged stands with greater structural and species diversity. Given enough time, western hemlock will gradually replace Douglas-fir or red alder in stands in western Washington or Oregon (Williamson and Twombly 1983), tanoak will replace Douglas-fir in southwestern Oregon and northwestern California (McDonald and others 1983), and white fir and incense-cedar will replace ponderosa pine in the mixed conifer forests of the Sierra Nevada (Laacke and Fiske 1983b).

Changes Because of Management

Timber harvesting and occasional wildfires have substantially reduced the acreage of old-growth forests; this is a continuing trend. Millions of hectares (acres) of old-growth forests have been harvested, typically by clearcutting, and replaced by young, more rapidly-growing plantations, especially in western Washington, western Oregon, and northwestern California.

Millions of hectares (acres) have also been logged selectively, many stands several times. Typically, the larger, more valuable trees were harvested, leaving substantial acreages with small trees of poor quality. This situation is particularly prevalent in California. Selective harvesting often caused a shift in dominant species from the more valuable pioneer species, such as Douglas-fir, ponderosa pine, and sugar pine to the shade-tolerant, commercially less valuable species, such as tanoak, Pacific madrone, grand fir, and white fir (Dunning 1923, Isaac 1943, Munger 1950).

Planting to restock burned-over and cut-over forest land began in earnest during the 1920's. Typically, Douglas-fir was planted in Washington and Oregon, and ponderosa pine in California. Initial results were highly variable, and failure was common, especially in reforestation of California brushfields (Ayers 1958). Seedling quality was often poor due to inadequate forest nursery practices, and seed came from trees that were not adapted to survive or grow well on the planted areas. Failures were also caused by excessive competition from shrubs and grasses and from browsing by animal pests. The oldest plantations are about 60 years old, and some have been commercially harvested.

Extensive planting following timber harvests began about 1960 (Tappeiner and others 1986), with most of the planted seedlings being ponderosa pine and Douglas-fir. Higher quality tree seedlings, produced through improved nursery technology and better control of competing plants and browsing animals resulted in plantations that generally met management expectations. In the 1970's, planting of true firs, western hemlock, and other species became more reliable and more common.

Planting rates of sugar pine and western white pine are presently low. The successful development of seedlings resistant to white pine blister rust (*Cronartium ribicola*) is expected to result in greater use of these species in reforestation programs.

Currently, about 121,000 ha (300,000 acres) are planted annually in western Washington and western Oregon alone (Chappell and Opalach 1984). The total acreage planted annually in all Pacific coast forests probably approaches 162,000 ha (400,000 acres). Ponderosa pine and Douglas-fir remain the most frequently planted species. Few sites are planted with hardwoods due to their relatively low values for timber products compared to conifer values.

Tree growth on some sites is reduced, at least temporarily, by heavy compaction of soils by tractors or rubber-tired machines used for moving logs, piling of logging debris, or removing unwanted trees or shrubs (Froehlich 1979, Adams and Froehlich 1981, Helms and Hipkin 1986). However, the precise relationships between soil characteristics, compaction, and long-term stand growth have not been well established. To reduce the risk of lowering productivity, many foresters have reduced usage of ground equipment, or restricted use to periods when soil conditions make heavy compaction unlikely.

Silvical Characteristics of Pacific Coast Species

Western Hemlock-Sitka Spruce Forests

Both western hemlock and Sitka spruce are prolific seeders, and their light seeds are transported long distances. Most young stands were established by natural seeding after clearcutting, and overstocking is common (Williamson 1976). Regeneration failures are most often caused by competing vegetation (Ruth and Harris 1979). Western hemlock is more shade tolerant than Sitka spruce and therefore replaces Sitka spruce in older forests. Where shade is removed, growth can be very rapid. Root systems are shallow, so the trees are vulnerable to the high winds of Pacific Ocean storms (Ruth and Harris 1979). Windthrow, dwarf mistletoe (*Arceuthobium* spp.) infection, and root diseases are serious problems influencing the choice of silvicultural systems in these forests (Ruth and Harris 1979).

Even-aged stands managed for timber production are grown to an age of 40 to well over 100 years (Harris and Johnson 1983). Well-stocked western hemlock-Sitka spruce stands are among the most productive in the world (Harris and Johnson 1983). Computerized models to predict growth and yield are being developed.

Douglas-fir Forests

Douglas-fir seed production is irregular. Germination and survival are best on mineral seedbeds (Isaac 1943). Shade tolerance is medium, but usually less tolerant than its principal tree associates (Minore 1979). Initial seedling survival and growth is favored by partial shade, but thereafter Douglas-fir grows fastest in full sunlight (Isaac 1943). Typically, partial shade is not needed for adequate survival of planted Douglas-fir seedlings, except in environments with extreme temperatures (Isaac 1943). Douglas-fir will be succeeded by western hemlock in the northern part of the range, or by tanoak in the southern part, unless large-scale disturbances caused by wildfire, extensive windthrow, or harvesting intervene (Williamson and Twombly 1983).

The most common competitors with Douglas-fir are hardwood trees, such as red alder, bigleaf maple, vine maple, and tanoak; and shrubs, such as snowbrush (*Ceanothus velutinus*), and salmonberry (*Rhus spectabilis*). Typically, these plants have to be controlled to achieve wood production objectives (Williamson and Twombly 1983).

Browsing of Douglas-fir seedlings by deer (*Odocoileus* spp.), elk (*Cervus* spp.), and mountain beaver (*Aplodontia rufa*) causes significant growth losses, and sometimes mortality (Black and others 1979). However, rarely do insects, other animal pests, or diseases influence cutting method decisions. Attainment of regeneration, harvest cost, and multiple-use objectives dominate this decision.

Douglas-fir stands are highly productive due to rapid tree growth and dense stocking. Production in well-managed stands is expected to be 30 to 50 percent greater than in natural unmanaged stands (Williamson and Twombly 1983). The maximum average wood production in managed, even-aged Douglas-fir stands will be achieved by rotation lengths of about 90 years of age, based on a computer simulation model developed by Curtis and others (1981). Maximum financial return, however, may be attained at a much earlier age.

True Fir-Hemlock Forests

Shade tolerance varies by species in mixed stands; Pacific silver fir, mountain hemlock, and white fir are the most tolerant, and California red fir, Douglas-fir, and the pines are the least tolerant. All species become established most effectively on mineral soil seedbeds, but tolerant species can also become established on thin litter seedbeds (Franklin and others 1983, Laacke and Fiske 1983a). Severe competition from grasses, sedges, lupines and other shrubs, and beargrass (*Xerophyllum tenax*); pocket gopher and deer browsing; and frost damage often inhibit seedling establishment and growth.

Initial tree and stand growth typically is slower than in forests at lower elevations, but growth later accelerates. Over the life of true fir-hemlock stands, the average annual wood production can exceed production rates of some lower elevation stands (Franklin 1981). However, rot due to decay fungi is so extensive in natural old-growth stands that actual harvests of usable timber typically fall far short of potential. Maximum average wood productivity in unmanaged, well-stocked, even-aged stands occurs at about 60 to 70 years of age for white fir, and at about 140 years for California red fir (Schumacher 1926, 1928). Computerized models for prediction of growth and yield have been developed recently for white fir in California (Wensel and Koehler 1985, Johnson and others 1986). A model for California red fir is being developed.

Annosus root rot (*Heterobasidion annosum*) is present in almost all true fir stands in California (DeNitto and others 1984). Annosus root rot and laminated root rot (*Phellinus weirii*) occur in many true fir-hemlock stands in Oregon and Washington (Franklin and others 1983). White pine blister rust and mountain pine beetle (*Dendroctonus ponderosae*) have all but eliminated the white pine component of many stands. Balsam wooly aphid (*Adelges piceae*) is a serious pest of Pacific silver fir and subalpine fir, especially on better sites (Mitchell 1966). Dwarf mistletoe frequently is a serious pest, particularly to western hemlock, California red fir, and white fir, seriously reducing the potential of the smaller trees to become vigorous large trees (Scharpf 1978). Windthrow can be a problem, depending on stand structure and topographic characteristics (Laacke and Fiske 1983a). Catastrophic fires at 100- to 400-year intervals in the Pacific Northwest have been significant historically (Hemstrom 1980). Prescribed fire has the potential to be an important management tool, but must be used very carefully as most species are very susceptible to heat injury (Franklin and others 1983).

Stand growth frequently is limited by available soil nitrogen (Powers 1982), most of which is stored near the soil surface (Pritchett 1979). Therefore, site disturbances to promote regeneration must be done with great care so topsoil is not lost (McColl and Powers 1986).

Hardwood Forests

Most hardwood trees are vigorous sprouters from stumps following harvesting, or from root burls or the base of the trunk following fire injury. Hardwood trees produce large quantities of seed, with considerable year-to-year availability. Many animals consume hardwood seed, often limiting the numbers of hardwood seedlings. For example, deer, cattle and rodents strongly limit successful regeneration of valley oak in California (Griffin 1980). Animals, particularly birds, are major dispersers of hardwood seeds. For example, seeds of the Pacific madrone are contained in berries that are highly favored by band-tailed pigeons and other birds (McDonald and Olson, in press). The seed is not digested by the birds and the still-viable seed is dropped to the ground as part of bird feces. The best seedbed for seedling establishment of small-seeded species, such as red alder, black cottonwood, and Pacific madrone, is bare mineral soil. Species with small seeds, therefore, typically occur in even-aged stands. Seedlings of species with large seeds, such as tanoak or California black oak, can become established on sites with shallow litter (McDonald 1978) and in the understory of conifer stands (Tappeiner and others 1986b). These species can occur in even-aged or uneven-aged stands.

Experience and research with planting hardwoods is limited, and the results have been mixed. Plantings of red alder and black cottonwood have generally been successful (DeBell and Turpin 1983). Planting tanoak in a large opening failed, probably due to excessive moisture stress (McDonald 1978). Testing of various methods of planting and seeding liveoaks is being conducted in southern California, where protection from rodents, deer, and cattle probably is essential for establishment.

Shade tolerance of hardwood trees varies from intolerant to tolerant. Seedling height growth varies from very slow (for example, tanoak and Pacific madrone) to quite rapid (for example, red alder and black cottonwood). Sprout growth typically is much faster than seedling growth, often 0.9 to 1.5 m (3 to 5 ft) per year for tanoak or Pacific madrone (McDonald 1978). Red alder seedling growth, and early sprout growth of tanoak or Pacific madrone, is more rapid than seedling growth of the associated conifers, so these hardwoods can be significant competitors where stands are being regenerated to conifers (DeBell and Turpin 1983, Minore and Kingsley 1983).

Of the native hardwoods, only alders, acting symbiotically with certain bacteria, have the capacity to convert atmospheric nitrogen to chemical forms that are available to other plants. Since available nitrogen in the soil typically limits stand productivity in Pacific coast forests, alders and certain shrubs (which also have this capacity) may improve forest productivity (Binkley and Husted 1983, DeBell and Turpin 1983).

Experience with managing stand density of hardwoods is very limited. Historically, stumpage values of hardwoods have been less than those for associated conifers, so there has been less economic incentive to manage hardwood stands for commercial products. Key silvicultural information, such as the relationships between stand density and wood production rates, or between stand density and seed production rates, is scant for many of the species. Computer models for simulating growth and yields for of mixed stands of conifers and hardwoods are being developed for use in southwestern Oregon and northwestern California.

Redwood Forests

Redwoods are prolific stump and root crown sprouters following fire or harvesting, but sprouting capacity significantly decreases in very large trees (Olson and Roy, in press). Typically, redwood forests have highly clumped distributions of trees due to the ring-shaped arrangements of trees that are sprouts from older "parent" trees. Redwood trees produce large quantities of seed, but viability commonly is very low (Olson and Roy, in press). A mineral soil seedbed is required for successful seedling establishment. The scarcity of established seedlings on undisturbed seedbeds may be due to root rots and damping-off fungi (Davidson 1971). New seedlings require more moisture for survival than do seedlings of associated species (Fritz and Rydelius 1966).

Insects, other animal pests, and diseases are seldom serious problems in redwood forests, and rarely influence the choice of cutting practices (Olson and Fiske 1983).

Shoot growth is best in full sunlight, often exceeding 4 feet per year, but is much slower when shaded (Olson and Roy, in press). Redwood can persist in dense shade, but control of the competing tanoak, Pacific madrone, and many shrubs is necessary to ensure redwood seedling survival and good seedling or shoot growth (Olson and Fiske 1983). When shoot growth is rapid, the very high stocking levels in redwood forests make these stands some of the most productive in the world (Olson and Roy, in press). A computerized model for predicting growth and yield has been developed for redwood stands (Krumland and Wensel 1981).

Mixed Conifer Forests

All mixed conifer species can be planted successfully (Laacke and Fiske 1983b). Except for the associated sprouting hardwoods, natural regeneration is almost exclusively by seed. Seed production is common but highly erratic (Minore and Kingsley 1983, Fowells and Schubert 1956). Tolerant species seem to have more consistent seed crops than intolerant species. A mineral soil seedbed enhances survival of natural seedlings of all species, and is required for most (Minore 1979).

Disease, insect, and animal pest conditions can strongly influence management decisions, particularly which tree species to favor and which harvesting methods to use. White pine blister rust continues to be a major disease of sugar pine, often preventing successful establishment. Root decay diseases such as annosus, Armillaria, and black-stain (*Ceratocystis wagneri*), often acting in concert with insect pests

such as bark beetles (*Dendroctonus* spp. and *Scolytus* spp.), cause wood production losses in mixed conifer forests (Smith 1978). All of the mixed conifers, except incense-cedar, can be infected by their own species-specific dwarf mistletoes, which sometimes cause major growth losses (Scharpf 1978) and predispose host trees to wood decay fungi and mortality resulting from damage caused by bark beetles. Damage caused by pocket gophers (*Thomomys* spp.), deer, and porcupines is a serious problem in some areas (Laacke and Fiske 1983b, Minore and Kingley 1983).

Competition from grass, forbs, ferns, shrubs, and hardwood trees is a serious problem affecting survival and growth (Laacke and Fiske 1983b, McDonald and Oliver 1983). Major competitors of conifers are manzanita (*Arctostaphylos* spp.), ceanothus (*Ceanothus* spp.), and bear clover (*Chamaebatia foliolosa*) shrubs; annual and perennial grasses; and tanoak and Pacific madrone hardwood trees (McDonald and Oliver 1983, Oliver 1984, Radosevich 1983, Tappeiner and Radosevich 1982). Control of these and other competitors is almost always needed to achieve wood production objectives (USDA Forest Service 1983).

When free of competition, early stem growth is most rapid in full sunlight. Maximum stocking levels are high, so potential stand productivity per acre is excellent (Dunning and Reineke 1933). Maximum average annual wood production in unmanaged, well-stocked, even-aged stands will be achieved with rotation lengths of about 65 years of age (Dunning and Reineke 1933). Recently, a computer model for predicting growth and yield was developed for mixed conifer stands in California (Wensel and Koehler 1985). Another model has almost been completed for southwestern Oregon (Ritchie and Hann 1987).

Cultural Practices for Pacific Coast Forests

The natural productivity of Pacific coast forests may be increased by application of several cultural practices, singly or in combination. These practices extend beyond regenerating stands and letting subsequent development proceed naturally. They include site preparation, planting (sometimes with genetically improved stock), control of inter-plant competition and animal damage, precommercial thinning, and fertilization. The two major purposes of cultural treatments are to shorten the period until desired trees again dominate the sites, and to enhance the quantity and quality of usable wood. Decisions regarding applications of the practices are based on a wide range of factors: objectives, characteristics of the stand and site, costs and benefits, and other managerial or operational considerations. Practices currently applied are described briefly in the following paragraphs.

Site Preparation

Site preparation is often needed to create suitable conditions for planting or to enhance establishment of natural regeneration. Also, site preparation treatments are used to lower the risk of wildfire by reducing the amounts of woody debris and other flammable materials after tree harvesting. Typically on steep slopes, the harvest residues are broadcast-burned, whereas in gentle terrain, unutilized material is piled by machine and burned.

The burning is done by prescription to avoid undesirable soil and watershed effects, such as excessive burning of the nutrient-rich litter layer and topsoil, formation of subsurface layers that resist water movement into the subsoil, and surface erosion. Concerns about effects of slash burning on human health have become an important issue in western Washington and Oregon (USDA Forest Service 1987) and in parts of northern California. Smoke also reduces visual quality, an important concern near the many major recreation areas, such as national parks. These concerns have resulted in increased restrictions by local governments on burning, limiting both when and how much land can be burned.

Use of machines to scarify ground, remove competing vegetation, and pile harvest residues must be done carefully to avoid excessive displacement of the litter layer and the topsoil, compaction, and subsequent erosion. Typically tractors are equipped with large rakes, instead of solid blades, to reduce displacement of litter and soil. Sometimes compaction effects are mitigated by "ripping" the soil--fracturing it to about 61 cm (24 in) depth by pulling metal teeth through the soil by a tractor. Risk of erosion is reduced by moving the tractor along the contour, or maintaining part of the litter layer, vegetation, or downed logs.

Herbicides are occasionally needed for site preparation.

Planting

Typically planting is done by hand, using a variety of equipment such as gasoline-powered augers, specially-designed planting hoes, or shovels, depending on slope and soil conditions. Machine-planting is more cost-efficient but is restricted to gentle terrain without excessive obstacles such as many large surface rocks or stumps.

Nurseries produce seedlings in small, soil-filled containers and with protected bare roots for planting. *Bare-root seedlings are used more frequently.* Improvements in nursery technology have increased survival rates of both kinds of planting stock.

A recent trend is to plant fewer trees per unit area. The primary advantage is to reduce seedling, planting, and precommercial thinning costs. The primary disadvantages are less chance that trees will be planted on the best microsites, fewer opportunities for selecting for high-quality trees during precommercial thinning, and increased risk of plantation failure because of unexpected mortality.

Release

Need for release from competing plants to ensure survival and rapid growth varies considerably in the Pacific coast forests, depending on species of potential crop trees and competing plants, site conditions, and management objectives. Generally, release is needed more on southern and inland sites, because of more severe competition for scarce soil moisture in drier environments. In the moister northern and coastal environments, release to reduce competition for light may be necessary.

Where release is needed, herbicides are the most common method on lands managed by State, industrial, and other private owners (Cafferata 1986). However, because of Federal court and administrative moratoriums, herbicide methods have not been used since mid-1984 on federally-owned Pacific coast forests (USDA Forest Service 1987, USDA Forest Service 1983). Long-term studies, although controversial, have demonstrated cost-effectiveness of herbicide treatments in Douglas-fir forests (Walstad and others 1986). General guidelines for herbicide use in Washington and Oregon have been summarized by Conard and Emmingham (1984a, 1984b, 1984c, 1984d).

Alternative methods for controlling competing plants have been tested extensively over the last decade because of public concerns about human health and the environment, the moratorium on herbicide use on federally-owned Pacific coast forests, and local needs to increase rural employment. Examples are hand-cutting of brush and hardwood trees, hand-weeding, use of paper or plastic light barriers, and livestock browsing and grazing. These experiments and operational trials have had mixed results (Bernstein 1978; Doescher and others 1987; Hobbs and Wearstler 1985; McDonald and Fiddler 1986; Mathews 1982; Peterson and Newton 1985; Sin 1985; Thomas 1983; Turpin, in press).

Hand-cutting is the most effective alternative method for controlling alder (Turpin, in press). In southwestern Oregon and California, the most promising low-cost alternative method for controlling shrubs, forbs, and grasslike plants is livestock browsing and grazing. However, major disadvantages limit the extent of its practical use. Many competing plants will not be eaten at all, or only during certain short periods, because they are unpalatable to most livestock. Sheep and, especially, goats may also eat the potential crop trees. Currently, there are too few livestock managers of cattle with experience in this special work. Sometimes killing of sheep and goats by mountain lions can be a serious problem.

Computer models for predicting growth of conifers at different levels of competition from shrubs and hardwood trees are being developed for the Douglas-fir and mixed conifer forests by research cooperatives in western Oregon and California, involving the timber industry, universities, and State and Federal agencies.

Precommercial Thinning

Often used in Pacific coast forests, early thinnings maintain or increase diameter growth rates and tree vigor, and remove defective trees. Surplus trees typically are cut by hand, using gasoline-powered saws. In gentle terrain, use of small machines to cut or masticate surplus trees is increasing. In some areas, demand has increased for small-diameter trees for use as fuel in electricity-generation facilities. This has reduced costs for precommercial thinning and increased machine-cutting and processing of small trees for fuel.

Infection of Douglas-fir stands in southwestern Oregon and northwest California by black-stain root disease

has been observed after some precommercial thinnings (Harrington and others 1983, Witcosky and Schowalter 1986), raising the concern that thinning may predispose Douglas-fir to infection. This possibility is being studied.

Thinning guidelines have been developed for all Pacific coast forests, except for hardwoods in southwestern Oregon and California.

Fertilization

Large-scale usage of fertilizer is presently confined to the Douglas-fir forests (Tappeiner and others 1986a). Typically, nitrogen fertilizer in the form of urea is dropped from a helicopter. Approximately 70 percent of the Douglas-fir stands in Oregon and Washington respond with increased growth. (Miller and Fight 1979). About one-third of recently planted Douglas-fir stands are expected to be fertilized (Chappell and Opalach 1984).

Research has been completed or is under way for other Pacific coast forests. The potential for good growth responses to nitrogen fertilization should be excellent for true fir stands (Powers 1982).

Animal Damage Control

The need for control of animal damage varies considerably in the Pacific coast forests (Black and others 1979). Nearly one-half of the lands reforested in western Oregon need some form of protection from animal damage, and about one-third receive protection (Campbell and Evans 1975). The severity of problems differs by forest type and damaging agent. Damage problems include browsing by deer and elk, and cutting or girdling of stems or roots by mountain beaver, pocket gopher, rabbit, hare (*Lepus* spp.), or meadow mice. In some areas, bark-stripping and girdling by bear (*Ursus* spp.) and porcupine cause serious losses in trees of sapling size and larger.

Methods of control include habitat modification, trapping and poisoning, concentrating hunting pressure, repellants, and physical barriers. Sometimes altering the vegetation, thus changing animal habitats, can effectively prevent animal damage. General strategies are to increase alternate preferred food sources or to modify habitats to make sites less attractive to pest animals (Borrecco 1976; Black and Hooven 1974; Campbell and Evans 1975, 1978).

Grass control is the main method for controlling damage caused by meadow mice. Trapping can be effective in preventing damage from mountain beaver in Douglas-fir forests (Borrecco and Anderson 1980) and from pocket gophers in mixed conifer and true fir-hemlock forests. Pocket gophers are also controlled by poison-baiting, applied by hand or with a special "burrow-builder" machine (Teipner and others 1983). Hunting is used occasionally to kill black bears that have learned to strip bark from valuable crop tees in redwood or Douglas-fir forests, or to prevent porcupine damage in mixed-conifer forests. Chemical repellants that either dispense offensive odors or make foliage less palatable are used to prevent damage by deer, elk, rabbits, or hares (Radwan 1969; Rochelle and others 1974). Fencing to keep out deer, elk, or livestock may be necessary to ensure regeneration of highly palatable hardwood species such as cottonwood and California black oak (Campbell and others 1985; Craven 1983; Longhurst and others 1962). Barriers to protect individual trees, such as degradable plastic tubing and small paper caps covering the topmost buds, are used to discourage browsing by deer, elk, and mountain beaver (Larson and others 1979; Crouch 1980; Campbell and Evans 1975).

Genetic Tree Improvement and Gene Conservation

Cooperative programs involving universities, the timber industry, and State and Federal agencies are working to improve the characteristics of most commercial forest trees for better growth, tree form, certain wood characteristics, and resistance to disease. For example, yields of Douglas-fir are expected to be increased by about 10 percent (Silen 1969). Also, successful regeneration of sugar pine and western white pine depends on developing genetic-based resistance to the white pine blister rust disease.

The primary methods of the genetic improvement programs involve selection of high-quality parent trees for breeding, testing of progeny, and developing ways of increasing seed collection or using cuttings from trees of demonstrated superiority. Some improved seedlings and cuttings have been produced, but gains in per acre yield have yet to be demonstrated.

Conservation of genes is a continuing consideration in tree improvement and tree harvesting programs. Typical conservation methods include two strategies.

First, genetically diverse seed is collected to regenerate stands after harvest cuttings or natural disturbances. Second, seed or cuttings from selected trees are put in storage. The seed is stored at very low temperatures to ensure continued viability. The cuttings are rooted or grafted onto other trees in "banks"--special areas designated for the preservation of the cuttings but from which cuttings can be made to move desired genetic material into other areas.

Research is continuing in the genetic "architecture" of the major commercial tree species to determine the characteristics of genetic variability in specific management areas. Results will help determine guidelines for selecting appropriate species and geographic seed sources for regeneration of certain kinds of sites and may also influence selection of commercial cutting practices.

Recent advances in biotechnology are expected to create significant opportunities in both tree improvement and gene conservation programs in the Pacific coast forests.

Commercial Cutting Practices for Pacific Coast Forests

Cutting practices are based upon ecological characteristics of the various species, physical conditions of the site such as slope and potential soil erodibility, economic considerations, and other specific management objectives for the forest stand. Typical objectives are to direct the productive capacity of the forests to achieve desired combinations of economic and amenity benefits. Given sufficient time and lack of major disturbances in the Pacific coast forests, trees will naturally occupy the available growing space; so management of forests for multiple use typically involves removing trees by harvesting to enhance conditions for other vegetation and dependent animals or to stimulate regeneration of desired tree species.

A wide variety of cutting practices have been used in Pacific coast forests--from cutting individual trees with no followup treatments to clearcutting followed by intensive cultural practices, including planting of genetically improved seedlings (Tappeiner and others 1986a). Each regeneration cutting method has advantages and disadvantages that promote or hinder achieving the management objectives for different resources, such as wood production, wildlife, watershed, soil, range, and landscape appearance. Choices are made after balancing the different resource objectives at the specific site. Typically, different cutting methods are needed to achieve the mix of management objectives for large forested areas. Depending on management objectives, several of the five major regeneration cutting methods discussed below could be effective for managing stands in each of the major kinds of Pacific coast forests. The key exceptions are also described.

Clearcutting

Clearcutting creates large openings, simulating the effects of major large-scale natural disturbances such as wildfires or windstorms. It has been used successfully in all Pacific coast forests, but most appropriately where shade-intolerant or moderately intolerant trees will be crop trees in new rapidly growing, even-aged stands.

Contrary to the common perception that clearcutting removes all trees, sometimes desirable groups or single small trees (advanced regeneration) are retained to become part of the new stand. Typically, this practice is limited to sites that will not be broadcast-burned after harvesting. For example, a recent survey of the National Forests in the Sierra Nevada showed that about 15 and 20 percent of the areas regenerated by clearcutting in the mixed conifer and true fir forests, respectively, have retained advanced regeneration (Smith, in press).

Clearcutting has been the most frequently used, even-aged regeneration cutting method in all but the true fir-hemlock forests. The reasons are that it is ecologically suited to the most valuable species, regeneration has been shown to be timely and reliable, and it is the most efficient silvicultural system for intensive management for wood products, particularly on steep slopes.

Small clearcuts, less than about 8.1 ha (20 acres), have worked well in the true fir-hemlock forests of the Pacific Northwest (Franklin and others 1983), but are considered riskier than the shelterwood system. Until recently, clearcutting true fir stands in California has not been sufficiently reliable. The best results in California typically occurred in narrow strips, up to about 36.6 m (120 ft) wide. In large openings natural regeneration of seedlings was often delayed by up to two or more decades, and planting failed. The

principle reasons were lack of shelter typically provided by nearby large trees, competition from grasses and other plants, damage by pocket gophers, poor-quality seedlings for planting, and logistical problems with planting at the optimum time. Recently, quality of planting stock has been significantly improved in California, and there are many examples of successful plantations following clearcutting of true fir stands.

There are other advantages of clearcutting that have significance in some situations and for some objectives. It is the most effective way to control spread of certain diseases, such as dwarf mistletoes and black-stain root disease. Clearcutting accompanied by intense utilization or prescribed burning of residue create large temporary fuel breaks in the forest, thus reducing the risk of uncontrollable and widespread wildfire. Forage habitat for livestock and many wildlife species, including deer, elk, and quail, is enhanced, and waterflow from forested watersheds is temporarily increased. Increasing water yields is becoming an important issue in the true fir-hemlock and mixed conifer forests of the Sierra Nevada Range.

Conversely, clearcutting has some drawbacks with respect to some objectives and may be inappropriate in certain situations. It provides the least shelter for seedlings, and thus may be undesirable on sites where hot, dry conditions and frost damage are likely to prevent successful establishment of regeneration. Such problems are especially important in true fir-hemlock forests (Franklin and others 1983). Clearcutting may temporarily eliminate habitat for certain species of birds and mammals that live primarily in dense stands of large trees or use it for cover, as is apparently the case for deer in southeast Alaska. The potential for erosion is temporarily increased until new vegetation develops on the site. Finally, clearcut openings are viewed as ugly and unnatural by some people.

Shelterwood

Shelterwood cutting mimics large-scale natural disturbances in which most trees are lost and the residual large trees may provide seed and shelter the natural regeneration from extreme heat and cold.

Shelterwood cutting provides considerable flexibility because the densities of sheltering trees and the periods of shelter can be varied to suit the ecological requirements of different species. It can meet the changing needs exhibited by some tree species in their early stages of development by first providing partial shade and later full sunlight.

Shelterwood cutting is appropriate and sometimes needed for regenerating hot, dry or high-elevation, frost-prone sites. Extensive acreages of shelterwood cuttings have been made in Pacific coast forests, particularly in the Douglas-fir, true fir-hemlock, and mixed conifer forests. Often seedlings have been planted to supplement natural seedlings. Many thousands of acres of "shelterwood" cuttings have been made, not because shelter was needed to establish the new stand, but because it was considered visually more appealing than clearcutting.

Shelterwood cutting offers some of the same advantages as described for clearcutting, albeit to a lesser degree. Forage habitat for some wildlife species and water yields are increased. Cutting units provide somewhat of a fuelbreak. The presence of residual trees limits erosion potential on some sites and provides a short-term appearance regarded by some people as more natural than other even-aged regeneration methods.

Use of the shelterwood system, however, is not feasible on sites where the sheltering trees will be blown over. It is also inappropriate when the sheltering trees have infestations of dwarf mistletoe. These limitations are particularly important in western hemlock-Sitka spruce and true fir-hemlock forests (Ruth and Harris 1979; Harris and Johnson 1983; Laacke and Fiske 1983a). The shelterwood system is not recommended for regenerating old-growth redwood (Olson and Fiske 1983) and red alder stands (DeBell and Turpin 1983). There are no demonstrated ecological benefits and many operational drawbacks.

Seed Tree

The seed tree system mimics large-scale natural disturbances which leave a few mature trees per acre to serve as seed sources for the new even-aged stand.

Although seed tree cutting has been successful in some Pacific coast forests, such as the true fir and mixed conifer forests in California (Gordon 1979; McDonald 1976), seed tree cutting has seldom been used for regenerating even-aged stands in Pacific coast forests. Regeneration for some species may

be delayed significantly because of long periods between good seed crops (Fowells and Schubert 1956). Where delays are excessive or the distribution of seedlings is inadequate, supplemental plantings are necessary. In other cases, natural regeneration results in many thousands of seedlings per hectare (acre)(McDonald 1976), necessitating extra-costly precommercial thinning. The few seed trees typically do not shelter seedlings, so the seed tree system does not provide the opportunity to moderate harsh environments as does the shelterwood system.

The primary advantage and use of the seed tree system lies in situations where the objective is to naturally regenerate extensive areas of timber in units too large to be seeded naturally from adjacent stands. In such cases, the retention of windfirm, seed-producing trees may be an economic alternative to planting. Such applications, however, may be limited on some sites by the common occurrence of severe windstorms and presence of dwarf mistletoe.

The seed tree system is not recommended for regenerating red alder (DeBell and Turpin 1983), Douglas-fir (Williamson and Twombly 1983), western hemlock-Sitka spruce (Harris and Johnson 1983), or old-growth redwood (Olson and Fiske 1983).

Group Selection

The small openings simulate small natural disturbances in stands. Group selection cutting has been used more frequently and more effectively than single tree selection cutting (see the following section) to regenerate or create uneven-aged stands, particularly where regeneration of the shade-intolerant species was needed. Before planting became reliable in the national forests in California, natural regeneration of seedlings was widely practiced, typically by cutting trees in small groups to create small openings favorable for establishment. The system is most useful in gentle terrain where silvicultural treatments are not severely constrained by topographic factors. With suitable care in the design and size of the openings, the group selection system can be used to regenerate any of the Pacific coast forests.

Group selection cutting, like shelterwood cutting, may create conditions needed for regeneration and yet moderate environmental extremes on hot, dry, and frost-prone sites. The small openings may be esthetically more acceptable to some people. There are important limitations to its use, however. Major among these are operational difficulties in the steep, rugged topography prevalent in many Pacific coast forests and the unsuitability of the method for controlling dwarf mistletoe, particularly in many hemlock and true fir stands. The many small openings are in effect little stands, and are difficult to monitor and treat subsequently in an efficient, cost-effective manner. Other disadvantages include destruction of small trees when large trees in adjacent groups are harvested and the need for more frequent entry to all parts of a stand, with consequent potential for increased soil compaction and root damage from heavy machinery.

Single Tree Selection

The cuttings simulate natural disturbances caused by the death of scattered trees. Regeneration occurs under the partial shade of larger trees, and seedlings must be able to survive and grow in a shaded environment with strong competition for soil moisture and nutrients. Unless stand density, and hence, wood production objectives are low, long-term application of this silvicultural system can be applied successfully only for species that are shade tolerant, such as western hemlock, redwood, white fir, and tanoak.

Repeated partial harvest cuttings, part of the single tree selection system, have been attempted on many thousands of hectares (acres) in Pacific coast forests. Extensive trials, however, clearly showed that the single tree selection system cannot be used successfully in old-growth forests of the Douglas-fir Region (Isaac 1956). There are many examples of high-grading forests that were done under the guise of practicing the single tree selection system. Large, high-quality trees were cut, leaving few or inferior, slow-growing trees that were more susceptible to attacks by insects and diseases. In these situations, establishing a new even-aged stand typically is the most efficient way of regaining desired wood productivity levels and other stand vigor qualities. Over the last two to five decades, there has been a major shift to even-aged management systems.

Where species requirements and terrain permit, single tree selection may be appropriate for creating or maintaining uneven-aged stands. Such stands are considered by some people to be esthetically preferable. The continuous forest cover thereby maintained may be desirable for some species of wildlife, and may offer greater protection of fish habitat,

soils, and streams. There are major limitations to application of the system in rugged topography, however, and in over-mature, old-growth forests. The latter may be riddled with disease, including dwarf mistletoe, and prone to windthrow. Harvest of trees in such stands commonly results in large proportions of unusable woody debris, and reduction of the fire hazard created by such material is difficult. Moreover, single tree harvest does not enhance forage habitat for many wildlife species, and all of the operational difficulties mentioned for small group cutting apply equally to single tree selection.

Another major disadvantage of the single tree selection system is the long-term difficulty with maintaining it in areas with periodic fires. Reforestation following fires creates new even-aged groups or stands. Reconverting these even-aged units back to desired multilayered stands by single tree selection cutting is very time consuming and inefficient, or impossible where fires are frequent and small trees are susceptible to heat damage.

Because of these drawbacks plus the slower growth of regeneration, the single tree system is not recommended for managing Pacific coast conifer forests of any species or type if wood production is an important objective (Harris and Johnson 1983; Williamson and Twombly 1983; Franklin and others 1983; DeBell and Turpin 1983; McDonald and others 1983; Olson and Fiske 1983; Oliver and others 1983; Minore and Kingsley 1983; Laacke and Fiske 1983a, 1983b).

Commercial Thinning

Commercial thinnings have become more common in the last two decades in the Douglas-fir, redwood, and mixed conifer forests, but use has varied, depending on the widely fluctuating values of small-dimension trees of the different species. There is considerable geographic variability in demand, because of differences in manufacturing and utilization capabilities. New light harvesting equipment and locally important demand for wood chips, firewood, and other small-tree products increase the economics of commercial thinning. Steep terrain restricts thinning opportunities on many Pacific coast sites; on some sites, it is operationally unreasonable; on others, costs may be prohibitive. Because of such constraints, most foresters envision fewer thinning opportunities than were anticipated previously. The general trends are for shorter rotations with no or few commercial thinnings in forests managed by the States or industry, and longer rotations with commercial thinning if terrain permits on Federal forests.

Ranges of thinning regimes have been tested, primarily for Douglas-fir (King 1986; Larson and Cameron 1986), ponderosa pine (Oliver and Edminster, in press), and white fir and California red fir (Oliver 1988; Cochran and Oliver, in press). Guidelines for appropriate residual stand densities have been developed for major forest types along the Pacific coast forests, except for hardwoods in southwestern Oregon and California.

All species should respond well to thinnings, except for those especially susceptible to decay following mechanical wounding during harvesting. True firs are very susceptible (Aho and others 1983), which strongly limits thinning opportunities, particularly on steep slopes where wounding is more likely.

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Effects of Timber Management Practices on Soil and Water

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Introduction

The purpose of this paper is to summarize what is known, in the United States, about the effects of various forest management practices on soil and water characteristics. We approach the topic from a general viewpoint and then proceed to more specific evaluations for the forest types considered in previous sections on silvicultural systems. The collective body of scientific knowledge on this topic is extensive and represents the most complete factual research available in the world. Seven decades of research by the Forest Service, universities, and private industry provide a firm foundation for evaluating impacts at different regional levels. In some instances, information is incomplete, poorly understood, or so variable that generalizations are not possible at this time; these situations will be identified in the text.

Water is the primary mechanism for transporting substances within and from forested lands. Thus, the simple hydrologic cycle for an undisturbed forest (fig. 1) is the key to evaluating the impacts of forest practices on soil and water resources. The processes of precipitation interception by plant surfaces, transpiration, infiltration of water into the soil, and stream runoff are common to all forests. However, the magnitude and relative importance of processes vary considerably between forest types. Furthermore, management practices alter these processes, which then produce changes in soil and water characteristics.

The cycling of nutrients is clearly linked with the hydrologic cycle (fig. 1). Nutrients taken up by trees are either stored in biomass or returned to the forest floor as the result of leaching of the canopy by precipitation or leaf fall. Subsequently, litter on the forest floor is subject to decomposition whereby nutrients are released and recycled or leached to streams and ground water. As with water, the nutrient cycle of forests undergoes alteration when management practices interrupt recycling processes.

Forest Management Practices

The major forest management activities affecting soil and water involve: (1) harvesting a stand of trees, (2) removing trees from the site, (3) regenerating a new stand, and (4) stand improvement between initial reestablishment and harvesting. Timber harvesting consists of cutting trees and possibly other vegetation on the logging site. The various methods and patterns of cutting are described in the section of this publication dealing with regional silviculture. Disturbances of the surface soil during the actual felling of trees are usually minor.

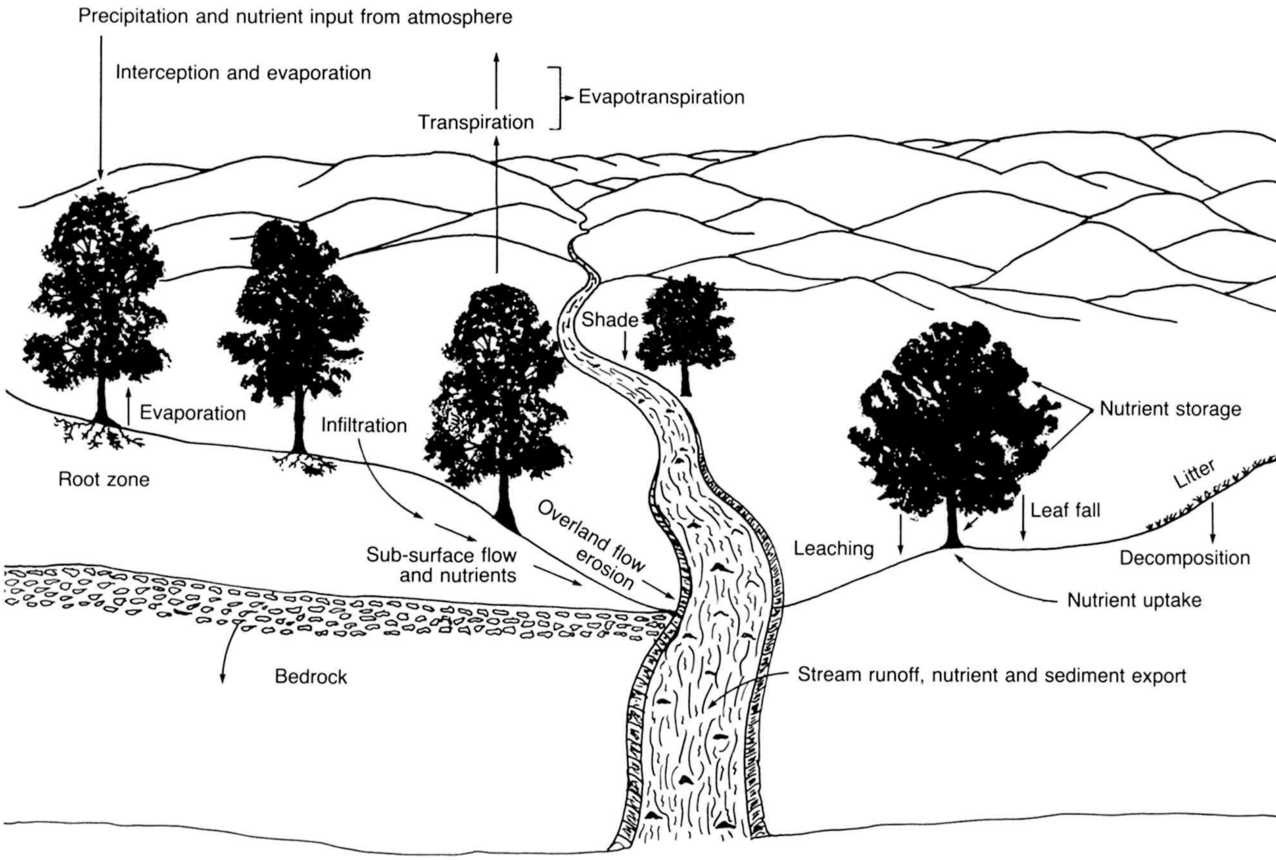

Figure 1--*The hydrologic cycle regulates the movement of materials on a forested landscape. Runoff across the soil surface is rare on forested land and tends to occur only if the soil is compacted during management activities. The processes of nutrient recycling are closely linked with the water cycle.*

After cutting, the trees are moved to a collection point and then transported to a mill or other processing site. The principal activities affecting soil and water during the transportation phase are skidding operations and road construction. After harvesting and removal of logs, the area may regenerate naturally by reseeding from trees on or near the site or by sprouting from roots and stumps. Frequently, forest managers choose to establish a new stand by planting, which may involve exposing the bare soil and removing competing vegetation and logging debris. In some cases, simply cutting and removing the trees may adequately prepare the site. In other cases, special site preparation techniques such as tractor raking, burning the debris, or spraying herbicides may be needed on the site. Once established, many stands adequately develop without additional treatment. However, it is often necessary to eliminate competing vegetation to obtain an acceptable growth rate of the standing tree firew Thinning is commonly used to induce faster growth. Additional nutrients are sometimes added in the form of fertilizers to encourage faster growth. All the above activities can affect soil and water although the magnitude of these impacts will vary across and within regions. The effect of these activities on water

yield and timing, water quality, and soil conditions are considered in a general sense in the following section. We do not examine the effects of practices on stream invertebrates and fish because this topic is examined in the chapter on wildlife.

General Effects on Soil and Water

Water Quantity

Transpiration, interception, and hence, evapotranspiration from the land (as depicted in figure 1) are usually reduced with harvesting or other silvicultural practices, resulting in more soil water being made available for the remaining plants and/or increased water movement to streamflow or ground water. The quantity of extra water produced depends on many factors, including the amount and type of forest vegetation, intensity and pattern of cutting, and climate of the area. Clearcutting produces the maximum reduction in evapotranspiration and the largest increase in soil water and streamflow. As cutting intensities decrease, less extra soil water is produced. The largest reductions in evapotranspiration usually occur in the first year after cutting. As the vegetation regrows, evaporation rates recover with a return to previous conditions depending on how fast the vegetation recovers. The extra water derived from cutting is usually viewed as a positive effect if water quality is not degraded. When large changes in evapotranspiration occur, the timing of runoff is also altered. Changes in the seasonal distribution of flows depend upon soil depth and the timing, amount, and form (snow or rain) of precipitation and other climatic conditions. Storm runoff may also be increased by cutting and the potential negative effects must be evaluated for specific sites.

Water Quality

Water quality characteristics most affected by timber harvesting are: (1) sediment (suspended and bedload); (2) dissolved nutrients (nitrogen, calcium, phosphorus, etc.); and (3) water temperature. Streams draining relatively undisturbed forests (even those on thin and erosive soils) are low in dissolved or suspended matter except in flood periods, high in oxygen content, and relatively low in temperature. In this natural condition most of the nutrients cycle regularly among the roots, canopy, and litter layer (fig. 1). Most of the precipitation is delivered to streams by subsurface flow, which contains low levels of dissolved nutrients. Overland flow from undisturbed watersheds is minimal, erosion is low, and sediment delivery to the stream is generally low. Further, the undisturbed forest shades the streams, and this reduces drastic fluctuations in water temperature. Timber harvesting removes different amounts of this protective tree canopy in various patterns depending upon the silvicultural system employed. Generally, under all silvicultural systems the closer the practices are to the stream channel the greater the risk of impacting water quality.

Erosion

Forest management activities associated with timber harvesting can affect the physical, chemical, and biological properties of the soil. If these activities increase soil erosion, then water quality may be decreased through stream sedimentation with an accompanying loss of long-term site and stream productivity. The type and magnitude of erosion depends on the amount of soil exposed by management practices, the kind of soil, steepness of the slope, weather conditions, and any treatments following disturbance.

Any management activity that exposes and/or compacts the soil and reduces infiltration can concentrate surface runoff and thereby accelerate erosion. Felling trees alone seldom causes erosion although some soil compaction and surface gouging may occur during this operation. In contrast, road building, skidding and stacking logs, and some site preparation activities can produce major soil surface disturbance that greatly increases the erosion on a site.

Landslides are frequently attributed to forest management. However, the kinds and structure of rock materials coupled with the amount and intensity of precipitation during storms also play a major role in causing landslides. Road construction in landslide-prone areas may sometimes increase slides, but these areas can be avoided by using current soil and geologic information for the areas being logged.

Nutrient Loss/Change

The nutrients contained in the trees, litter, and soils in forested areas can be affected by various forest management practices. Cutting alters the processes that regulate nutrient recycling, which frequently

accelerates nutrient leaching and loss in dissolved form. Practices that increase the erosion of soil particles from the site also remove nutrients because many of the important plant nutrients are attached to the eroded soil particles. The soil nutrient regimes on a particular site can also change when one forest type is changed to another because tree species differ in ability to retain and cycle nutrients. Fertilization of forests affects soil nutrients by providing additional plant nutrients for growth. The type of logging may also affect the amount of nutrients removed from a site. For example, whole tree logging, which removes most of the aboveground tree parts, is of concern to many forest managers because of the potential long-term effect on soil fertility and site productivity. Whole-tree timber harvesting removes two to five times the amount of nutrients from the site compared to when only the bole is removed.

Fire

Fire has always been a major factor affecting the composition and function of forests. Prescribed fire, that is, fire to accomplish specific planned management objectives, is used for a variety of purposes, including preparation of sites for regeneration or planting, reduction of fire hazard, control of undesirable plants and diseases, improvement of forage for grazing, and improvement of wildlife habitat. The effect of fire on soil and water primarily depends on the intensity of fire. Generally, a low-intensity fire increases the availability of nutrients to plants. It generally does not increase soil erosion. Intense, hot fires may completely burn the forest floor, expose mineral soil, and accelerate soil erosion in steep terrain. However, when hot fires are conducted under proper weather and fuel conditions, this need not be the case. Substantial quantities of nutrients, particularly nitrogen, are volatilized and lost from the site during hot burns. The frequency of burning and subsequent management practices used after burning influence the long-term effect of fire on soils.

Herbicides

Herbicides are widely used in forestry to prepare a site for a new stand and to release desirable tree species from competing vegetation. The most commonly used chemicals are dicamba, glyphosate, hexazinone, picloram, 2,4-D, and triclopyr. Some new herbicides such as imazapyr, metsulfuron methyl, and sulfometuron methyl are becoming available for use. Combinations of these herbicides are particularly effective on difficult-to-control competing vegetation.

If used according to label instructions, forestry herbicides are considered to be environmentally safe in terms of direct effects. These chemicals are low in toxicity, do not persist in the environment for long periods of time, and are not used frequently in the rotation of any one stand. Persistence is affected by individual chemical characteristics, climate, photodegradation, soil type, and microbial decomposition. Suitable application technology (that is, granular formulations, drift control agents, raindrop spray nozzles, equipment guidance systems, for example) exists to safely control herbicide placement. Most problems arise from inadequate planning, care, or inability to ensure herbicide placement on the target vegetation.

The effects of herbicides on soils can be considered to be positive. Using herbicides to control competing vegetation reduces soil disturbance and erosion compared to site preparation with machines. Some herbicides like picloram and hexazinone are soil-active and can be absorbed by roots of beneficial plants as well as by competing vegetation. Glyphosate represents the other end of the spectrum. Although water soluble, it is strongly bound by organic matter and clay minerals.

Off-site movement of herbicide residues is strongly affected by herbicide type and placement, application rate, mobility, and climatic events after application. Soil organic matter content and hydrologic condition are important in retaining chemical residues on site. Water quality is usually not affected if adequate buffer strips are maintained around perennial streams so that direct applications to streams are avoided. Also, care must always be taken in handling concentrated solutions during the transportation, storage, and mixing phases of herbicide use.

Effects in Different Forest Types

Western Inland Conifers

The western inland conifer type is located in the Rocky Mountains where it extends from Canada to the Mexican border. Forest types in this region range from the Rocky Mountain subalpine forests in Colorado and Wyoming to southwestern ponderosa

pine stands in Arizona and New Mexico. The northern Rocky Mountain province comprises the mountainous headwaters of the Columbia and Missouri drainages. The remaining portion of the central and southern Rocky Mountains are located mainly in the upper and lower Colorado River basins.

The climate in this region varies widely. Generally, precipitation ranges from more than 760 mm (30 in) annually at higher elevations to less than 510 mm (20 in) in lower elevation forests. At higher elevations, and on more northerly sites, the climate is cold and wet with strong persistent winds on ridge crests and summits throughout the year. More than 75 percent of the annual precipitation is snow, which is moved by wind from exposed sites to sheltered spots where it forms deep drifts. In contrast, the climate at lower elevations in ponderosa pine forests in the Southwest is moisture deficient through much of the growing season. The average precipitation is about one-half snow and varies from 380 to 635 mm (15 to 25 in) annually.

Geomorphology, geology, and soils vary widely throughout the western inland conifer type. Noteworthy is an area in the northern Rocky Mountains called the Idaho Batholith. The geology of this area is granitic rocks and the soils derived from them are extremely erodible and present special management problems.

Water Yield--Our understanding of water yield in the inland conifer type is based primarily on studies in the upper and lower Colorado River basins, where about 2.18 million hectare-meters [360 mm](190 million acre-feet [14.2 in]) of rain and snow fall each year and where more than 90 percent of it evaporates (Hibbert 1979). With such large amounts of water being returned to the atmosphere, even slight reductions in evapotranspiration by vegetation and snow management is limited to certain cover types, and only about 16 percent or 10.5 million hectares (26 million acres) of the basin is sufficiently vegetated for water yield improvement measures. In addition to these physical constraints, target water yield potentials for the Colorado River Basin must be adjusted for variable constraints, such as multiple-use considerations, social-political factors, economics, and watershed condition (Schmidt and Solomon 1981; Solomon and Schmidt 1981).

Water yield improvement in the Colorado River basin is based on the premise that streamflow and/or ground water are increased by an amount equal to the net reduction in evapotranspiration. Little opportunity exists for reducing transpiration where precipitation is less, and evapotranspiration greater, than 457 mm (18 in) annually because rains do not penetrate far enough into the soil, and one cover type is about as efficient as another in using available water. At the other extreme (cold, wet climate), opportunities for decreasing transpiration are limited because water use by plants already is low, and further reductions are difficult to obtain. However, in these cold, wet climates, water yield can be increased by snow management.

The effect of different timber harvesting systems on water yield improvement depends largely on the nature of precipitation--whether it is predominantly rain or snow. In all areas, clearcutting usually produces maximum increases in water yield compared to thinning and patch cutting. Thinning is not an effective method for increasing water yield where summer moisture is less than plant water demands. In this situation, plants remaining after thinning are capable of using the additional moisture gained from thinning. As a general rule, uniform thinning of forest stands at lower elevations and in the Southwest must remove about 50 percent of the crown cover before water yield increases appreciably (fig. 2). For this reason, silvicultural systems using shelterwood or individual tree selection methods of harvest are not as water productive as patch cutting and clearcutting.

In contrast, at higher elevations and in more northerly areas where snow makes up a larger percentage of the precipitation, water yields may be increased substantially by thinning or by patch cutting to create small openings (Troendle 1983). Yield increases occur here because of both snow redistribution and a reduction in interception loss (Troendle and King 1985).

Water yield increases gained by timber harvesting may be sustained for variable lengths of time. In the more arid Southwest, gains are short lived and are usually lost within 10 years (Baker 1986). In contrast, water yield increases in higher elevation mixed conifer types may be sustained for at least 40 years because it takes a long time under these cooler climatic conditions for forests to regenerate.

Streamflow Timing--The effect of timber harvest on peak discharges in the Rocky Mountains depends on the pattern and scheduling of cutting. On partially clearcut areas, melt is advanced in openings, but

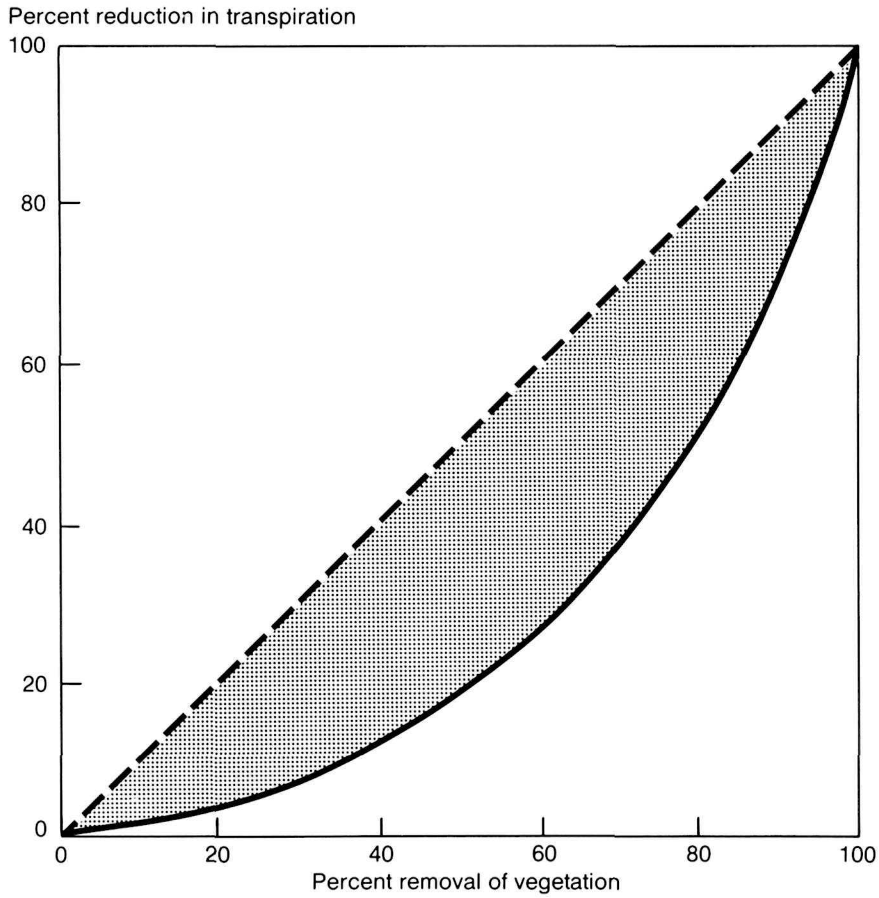

Figure 2--*Hypothetical reduction in transpiration as a function of uniform removal (thinning) of trees under conditions that vary from unlimited soil water availability to trees (shaded portion tending toward broken line) to definitely limited availability (shaded portion tending toward solid line) (Hibbert 1979).*

the net effect is to desynchronize the flows so that no increase occurs in peakflows (Troendle 1983).

When watersheds are clearcut, peak discharge can be increased up to 50 percent. Since recommended harvest design for water yield improvement is uniformly spaced clearcut patches, 3 to 8 tree heights in size and occupying about 30 to 40 percent of the total watershed areas, there should not be any significant effects on peakflows associated with increasing water yield.

Erosion and Sedimentation--Accelerated surface and mass erosion are often easily caused by silvicultural practices in the inland conifer type. Under undisturbed forest conditions, surface erosion is quite low because enough material is on the forest floor to protect the soil surface. Here, soil permeability is normally high. Following timber harvest however, surface erosion usually accelerates in response to disruption of soil structure during logging (roads, skidtrails, and landings), removal of protective cover, increased raindrop impact and wind movement, and reduced infiltration rates (resulting from compaction) that create overland flow. Amount of erosion and sedimentation vary widely within the inland conifer type. Logging on coarse-textured, permeable soils with careful road building produced little sediment yield in the Rocky Mountains of Colorado (Leaf 1966). In southwestern ponderosa pine forests, sediment yields varied from 2.9 tonnes/ha (1.3 tons/acre) when 31 percent of the basal area was removed to 60.5 tonnes/ha (27 tons/acre) under 100-percent removal (Ward and Baker 1984).

Disturbance by road construction can contribute substantially to erosion in sensitive areas. Roads accelerate surface erosion by increasing slope

gradients on cut and fill slopes, intercepting subsurface waterflow, and concentrating overland flow of water on road prisms and in channels (Megahan 1981). A study by Megahan and Kidd (1972) illustrates the relative effects of timber harvesting in relation to road construction on steep granitic slopes in southern Idaho. Surface erosion rates on an area influenced by ground cable logging were increased 1.6 times over undisturbed erosion rates for a 6-year study period. In contrast, erosion rates on logging roads were 220 times greater than on undisturbed sites. Although large erosion rates from roads occur immediately after logging, these decrease rapidly after disturbance. Megahan (1974) found that over 80 percent of the accelerated surface erosion on roads in granitic soils occured within the first year after disturbance. Within 5 years, erosion rates were greatly reduced but still greater than under undisturbed conditions, primarily because of erosion on road cut slopes.

Water Quality and Temperature--Logging affects water quality mainly through erosion and sedimentation, nutrient release, and modification of water temperature. Logging systems that create large amounts of surface disturbance, for example, clearcutting using tractors, on steep slopes lead to high rates of erosion and sediment movement, which decrease water quality substantially. Although measurable amounts of nutrients can be released into the soil solution following logging, these nutrients rarely move through the soil mantle in sufficiently large quantities to affect stream chemistry (Clayton and Kennedy 1985). However, timber harvesting can increase water temperatures in streams if trees shading channels are removed. Maintenance of shade corridors along streams and judicial placement of clearcut units can largely prevent adverse increases in stream temperature.

Soil and Soil Nutrients--Timber harvesting affects physical, chemical, and biological soil properties. Most physical effects result directly from logging and most frequently involve soil compaction. Soil chemical properties and soil nutrients are affected primarily by nutrient loss and depletion through biomass removal. Biological processes most readily affected by timber harvesting are nutrient transformations and the availability of nitrogen and phosphorus.

Soil compaction results from ground-based timber harvesting. Soils in undisturbed forests have high porosity and are easily compacted by logging equipment. Compaction not only slows down water entry into the soil but can also reduce long-term rates of tree growth. The degree of compaction resulting from timber harvesting depends on type of logging equipment used, physical properties of the soil, amount of organic matter, and moisture content of the soil. Generally, volcanic-derived soils are compacted more easily than granitic-derived soils and may remain altered for more than than 23 years (Froehlich and others 1985).

The impact of clear, shelterwood, and group selection cutting on nutrient budgets was studied in a western larch-Douglas-fir forest in northwestern Montana (Stark 1979). The most intensive silvicultural treatment (clearcutting) removed less than one-quarter of 1 percent of the nutrients contained in the entire ecosystem (parent rock, roots, soil, litter, and aboveground biomass). Although only a small percentage of total nutrients was removed, it is not known how this treatment affected available nutrients.

Pacific Coast Conifers

The Pacific coast conifer type extends from southwestern Alaska through the Cascade Mountains in western Washington and Oregon and southward into the Sierra Nevada Mountains in northern and central California. This type also includes the Pacific Coast Mountains in northern and central California. Regional geology ranges from extrusive volcanics in Washington and northern California to granitic in much of the Sierra Nevada. Most coastal mountains in California are of sedimentary origin. Forest vegetation in Washington and Oregon consists primarily of Douglas-fir and western hemlock. Mixed conifer species and ponderosa pine are important forest types in California, while in Alaska, spruce-fir forests predominate.

Climate throughout the Pacific coast conifer region is generally characterized by heavy fall and winter precipitation and relatively dry summer periods. About 80-85 percent of the annual precipitation occurs between October and April (Harr 1983; Kattelmann and others 1983). In Oregon and Washington, average annual precipitation ranges from about 1015 mm (40 in) in the inland valleys to more than 3810 mm (150 in) along the Pacific coast. At the upper elevations, snowpack depth may reach 255 cm (100 in) in some years but generally is 90 to 150 cm (35-60 in). Below about 2290 m (7,500 ft), snowpacks are transient, rarely remaining longer than 1-2 weeks and usually

melting in 3-4 days during subsequent rainfall (Harr 1983). The general climate of the Pacific Northwest is further characterized by mild temperatures with prolonged cloudy periods during the rainy season, muted annual temperature extremes, and relatively narrow diurnal temperature fluctuations. The Sierra Nevada area is distinguished by relatively high precipitation, moderate evapotranspiration, and a deep seasonal snowpack above 1525 m (5,000 ft). Annual precipitation may vary from more than 1650 mm (65 in) to less than 940 mm (37 in)(Kattelmann and others 1983).

Water Yield--Western Washington and Oregon are "water rich" regions, with 80 percent of the annual precipitation and streamflow occurring between October and April. Water yield is increased about 355 to 535 mm (14-21 in) after clearcutting and 100 to 305 mm (4-12 in) after shelterwood and patch cuts (Harr 1983). Although immediate water yield response is substantial, the estimated sustained annual increase from large watersheds is as low as 3-6 percent, because only small portions of watersheds can be maintained in recently logged conditions and capable of yielding maximum amounts of water. In coastal areas where fog is common, water yield might be reduced by cutting patterns that eliminate precipitation normally received as fog interception and drip (Harr 1982). Water yield increases are also dependent upon precipitation and are greatest during wet years, when most of the annual increase occurs during fall and winter.

Fifty percent of California's usable water comes from the Sierra Nevada. Vegetation manipulation and snowpack management can be used to increase runoff from small watersheds by reducing evapotranspiration losses, snow interception by canopy, and snow evaporation (Kattelmann and others 1983). Small clearcuts or group selection cuts that create small openings of 0.4 ha (1 acre) or less, oriented in a north-south direction, are best for both increasing and delaying water delivery from forests on the Sierra's west slope. However, water yield increases of 40 percent measured on small catchments can drop to 0.5-2 percent for an entire management unit because only a small number of openings are cut at one time. The number of openings are limited by physical and management constraints and multiple-use/ sustained-yield guidelines. It is estimated that water production from national forest land in the Sierra Nevada can be increased only about 1 percent (5 mm or 0.2 in) through intensive forest watershed management.

Streamflow Timing--Increases in peakflows following logging in Oregon are more closely related to the extent of soil compaction than to silvicultural systems used (fig. 3)(Harr and others 1979). This generalized relationship ignores other important factors such as proximity of compacted areas to streams, continuity of compacted areas so that overland flow reaches streams, interception of subsurface water by road cuts and ditches, and watershed soil and physiographic characteristics. Nevertheless, percent of compacted soil on a watershed appears to be a good indicator of increased size of peakflows. Soil disturbance may significantly affect erosion by increasing peakflows and must be considered when designing culverts in headwater areas. Increased peakflows may produce sedimentation downstream, but are probably of little importance in flooding of lowlands downstream because only small peakflows are affected. For example, on the north coast of California, selection cutting and tractor yarding of a redwood and Douglas-fir forest did not significantly affect large peakflows,although the first peakflows in early fall were increased by 300 percent. These initial peakflows were small in magnitude and were of little or no consequence downstream (Ziemer 1981).

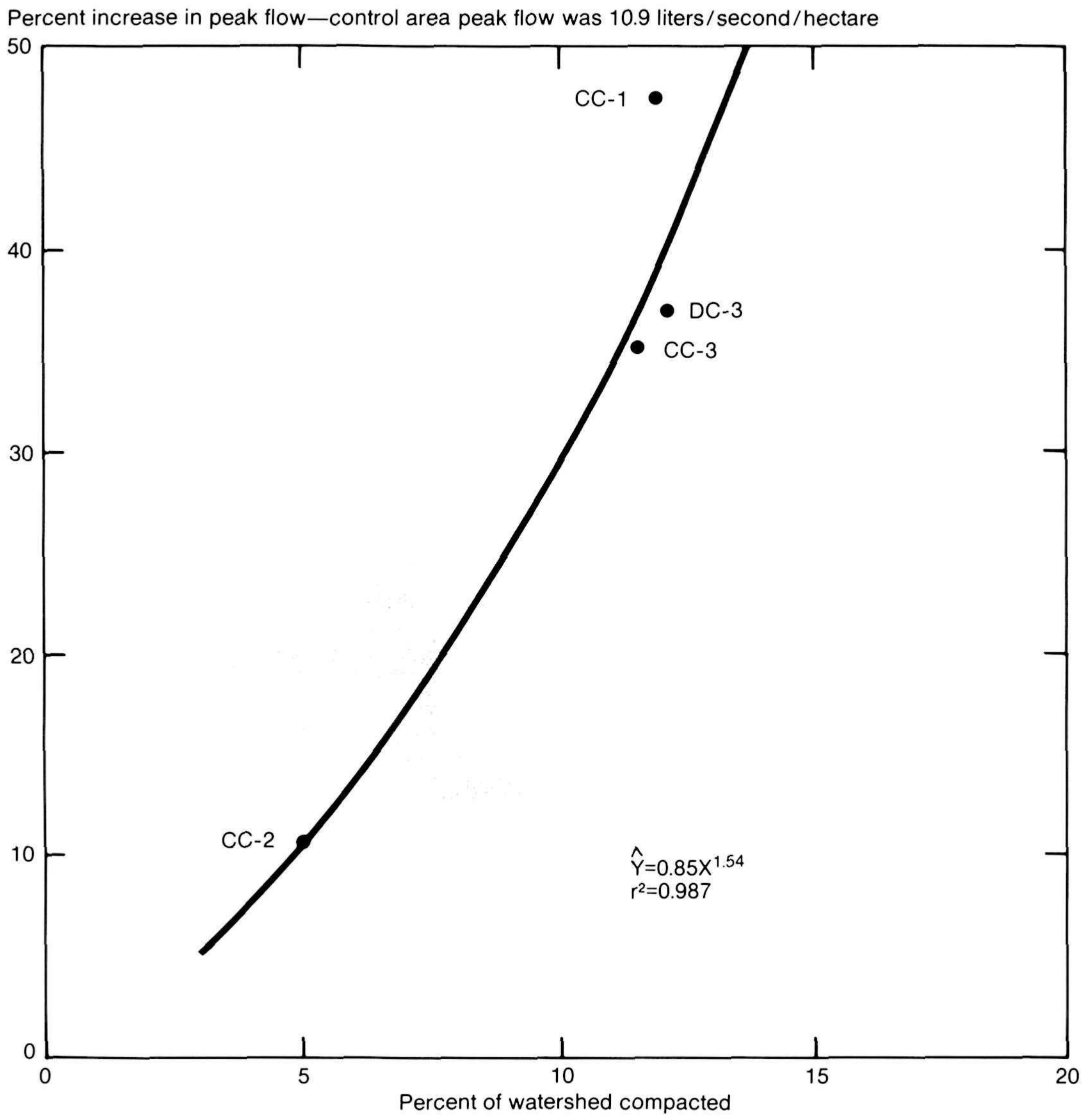

Figure 3--*Relationship between soil compaction and increase in size of peakflow. CC-1 was a shelterwood harvest where 50 percent of the total basal area was removed. CC-2 was a small clearcut harvest making up 30 percent of the watershed. CC-3 was completely clearcut. DC-3 was a watershed in which 65 percent of the area was clearcut by high lead logging (Harr and others 1979).*

Erosion and Sedimentation--The amount of stream sedimentation resulting from timber harvesting depends largely on the amount of disturbance occurring during logging and subsequent erosion. Soil disturbance is more related to type of logging operation (tractor, jammer, and so forth) than to silvicultural system (Rice and others 1972). A major disturbance during timber harvesting is road construction. Substantial increases in sediment yields have been noted on watersheds during and following the construction of forest roads. Erosion rates on roads and landings in southwestern Oregon were 100 times those on undisturbed areas, while erosion on harvested areas was 7 times that on undisturbed sites (Amaranthus and others 1985). The two primary processes by which roads contribute sediment to stream systems are: (1) by increasing the incidence of mass soil failures in a watershed, and (2) by surface erosion of road prisms and the transport of this material into streams. However, properly constructed

roads on gentle to moderate slopes on stable topography present little hazard. But both construction difficulty and erosion hazard increase rapidly when roads are pushed into steep terrain, cut into erosive soils or unstable slopes, or encroached on stream channels (Stone 1973).

Landslides are an important source of sediment in both undisturbed and managed steep drainages in the Pacific Northwest. Human activities probably have little effect on large, deep-seated, massive earthflows. However, smaller and shallower avalanche and debris torrents are most prone to be influenced by forest management activities, and landslide inventories indicate roads have been the major activity associated with accelerated shallow landsliding (Ice 1985). Proper forestry practices addressing drainage, road construction and maintenance, compaction of road fill, and the incorporation of organic debris can reduce landslide related erosion (Ice 1985; Barnett 1983).

Water Quality and Temperature--Timber harvesting also affects water chemistry by interrupting onsite nutrient cycling processes and allowing soluble plant nutrients to be leached through the soil into streams draining harvested watersheds. Type of logging operation and postharvest slash disposal treatments have an important effect on the amount of nutrients moving into streams. For example, partial clearcutting and patch cutting Douglas-fir in Oregon did not significantly affect soil chemistry (Fredriksen 1971). In contrast, clearcutting and burning slash increased nitrate nitrogen and potassium in streamflow. Nitrate concentrations returned to prelogging levels 6 years after logging and potassium within 2 months (Brown and others 1973). Although nutrients were lost, water quality was not degraded nor was the productivity of soils reduced.

Timber harvesting systems that remove or modify riparian vegetation in the immediate vicinity of a stream can increase water temperature. When forests are clearcut and logging debris removed, annual maximum stream temperatures can increase as much as 15.6 °C (28 °F) and mean monthly temperatures 7.8 °C (14 °F)(Brown and Krygier 1970). Temperature increases are greatest for very small streams. No increase in stream temperature should occur when buffer strips 15.2-30.5 m (50 to 100 ft) wide are left while harvesting 25 percent of the area in clearcut patches (Brown and others 1971).

Soil and Soil Nutrients--Effects of clearcutting on soil solution chemistry vary from site to site in the Pacific coast conifer type. A study in a 43-year-old second-growth Douglas-fir forest showed that only small changes occurred in the nutrients contained in the surface soil layers of undisturbed areas and those harvested by clearcutting (Cole and others 1975). In contrast, clearcutting a 60-90-year-old forest in Canada dominated by western hemlock, Douglas-fir, and western red cedar substantially increased the potassium and nitrate in the soil solution (Kimmins and Feller 1976). In both studies, logging slash was burned. Following burning, ion concentrations in the soil solution increased twentyfold to twenty-five fold.

Perhaps the most important changes occurring in soils resulting from timber harvest are soil disturbance and compaction (Cromack and others 1978). Compaction and disturbance occur primarily during road building and harvesting activities. Generally, the more complex expensive yarding systems designed to operate on steep terrain have much less impact than tractor logging on similar slopes. It is recommended that logging with tractors be restricted to slopes of less than 50 percent and compact or deeply disturb no more than 20-25 percent of the area. In contrast, skyline or balloon yarding compacts and disturbs less than 8 percent of the area. The proportion of selectively cut areas that are disturbed and compacted by tractors and skyline logging systems are similar because access is needed to all areas of a harvest unit regardless of whether it is being thinned or clearcut.

Northeastern Conifers

The northeastern conifer region supports stands of spruce, fir, and pine in the northern part of the United States between Minnesota and Maine. These species are intermingled with the maple-beech-birch type in New England and aspen-birch type in the upper Lake States. Scattered islands of red spruce and white pine stands extend south in the Appalachian Mountains to Georgia.

Most of the region has glaciated landscapes and the soils are derived from sandy outwash and cobbly moraine materials. A typical landscape has low relief with meandering water courses but is mountainous in the eastern and southern parts. Lakes and swamps are common, particularly in the upper Midwest section. Elevations extend from sea level in Maine to over 1830 m (6,000 ft) in the White Mountains and the

Appalachians. Annual precipitation ranges from 510 mm (20 in) in the western part of the region to over 1520 mm (60 in) on the higher mountains of the eastern ridge crests. The winters are cold and the summers are cool. Nearly all the forests in the northeastern conifer region have been harvested or burned at least once and the current stands are second growth or plantations.

Water Yield--Water yield response to timber harvesting in northeastern conifers is not well understood. Strip cutting 40 percent of a black spruce bog did not change the water table or streamflow over a 5-year period following cutting (Verry 1980). Clearcutting caused the range of water table fluctuation to increase elevation but not change annual streamflow. Water levels in the clearcut bogs during wet periods were higher than predicted because of a decrease in interception loss and lower during the dry period because of higher evapotranspiration (Verry 1980). Clearcutting upland hardwoods or conifers increases streamflow by 9-20 cm (3.5-8 in) and flows return to preharvest levels in 12-15 years (Verry 1986).

Stand composition also affects water yields in northeastern conifer forests. A study in lower Michigan showed that replacing hardwood stands with pine plantations decreased water yields by one-fifth to almost one-third (Urie 1977).

Streamflow Timing--Clearcutting an aspen stand in north-central Minnesota increased both snowmelt and stormflow (Verry and others 1983). Peak discharges from snowmelt were increased 11-143 percent and occurred about 4 days earlier during a 9-year period after clearcutting. Rainfall peak discharges increased as much as 250 percent but were only sustained for the first 2 years following cutting. Stormflow volumes increased 170 percent for 2 years, whereas snowmelt volumes did not change significantly. Partial cutting about one-half of the watershed reduced peak snowmelt discharge because snowmelt was desynchronized in cleared and forested areas. Other research in Wisconsin showed that planting red pine plantations may delay summer flood peaks (Sartz 1976).

Erosion and Sedimentation--The sparseness of streams, porous soils, and more than 760 mm (30 in) of precipitation create a hydrologically stable environment in the northeastern conifer region. Disturbances generally heal quickly. Cut slopes on roads and roads crossing streams have long been recognized as the primary sources of stream sedimentation. Some of the deep unconsolidated gravels and sands of glacial origin erode badly if disturbed by road construction. However, efforts are being made to better locate and design roads to minimize this impact (Stone 1973). Less expensive roads, having lower standards, are being tested as a measure for reducing environmental impacts as well as construction costs (Kochenderfer and others 1984).

Some cultural techniques can cause major site disturbances and accelerate erosion. In the past, using heavy equipment to "rake" logging debris and competing plants into windrows removed the thin organic surface layers, and the mineral soil was inadvertently scooped up (Sajdak 1982). This practice resulted in spots of soil erosion and the loss of soil fertility. This type of site preparation has largely been discontinued as a result of better research and soils information.

Water Quality--The dissolved nutrient content of water coming from forested areas is influenced by management. Ohmann and others (1978) identified significant increases in iron, manganese, potassium, and phoshorus in streams draining clearcut black spruce stands. This effect disappeared within 4 km (2.5 miles) of the site. Heavy thinning of a red pine plantation caused large increases in discharge and removal of nitrates, potassium, and calcium (Haberland and Wilde 1963). In a practical sense, the effects of harvesting and thinning on downstream water quality are not important because the treated areas are a very small part of the watershed.

Soil and Soil Nutrients--Most forest management practices affect soils. Perhaps even less than in other regions, tree cutting alone seldom causes much soil disturbance. The most obvious effect of harvesting is often the loss of surface litter due to more sunlight, higher surface temperatures, and lack of litter replenishment. Soil erosion probably does not affect nutrient cycling except in localized areas where road construction severely disturbs the site.

"Whole-tree" harvesting is currently being practiced in some northeastern conifer stands. This practice is of concern because it removes two to four times the amount of nutrients from the site as conventional methods (Smith and others 1986). Many investigators feel that shallow and sandy soils are more vulnerable to damage by whole-tree harvesting than other soils

because a high proportion of the nutrients on these sites are in the vegetation (USDA Forest Service 1984; Green and Grigal 1980). Gordon (1981) observed that dry outwash sand and organic soils in Canada may not sustain full-tree logging. Research findings on this problem have been mixed but it is generally agreed that more research is needed before definitive answers can be given (Perala and Alban 1982; Adams and Boyle 1979).

Fertilization of northern conifer stands has been tried in a few places. This was partly an effort to reduce the adverse nutritional effects of whole- tree logging but mainly to determine if it is an economically sound practice. The tentative conclusion, based on findings in the United States (Ohmann and others 1978) and Canada (Krause 1981), is that chemical fertilizers have not proven to be of economic value in conifer silviculture in the northeast. They are of value for nonwood objectives such as for Christmas trees, ornamentals, and for woody vegetation used to stabilize eroded areas (Leaf and others 1975).

Fire is a silvicultural tool used occasionally in the northeastern conifer region to clear the site of logging debris and encourage certain tree and shrub species. Fire has been used to establish jack pine in the Lake States and to improve blueberry patches. The effect of fire on soil and water in this region is similar to that in other regions. A low-intensity fire causes cycling of some nutrients and may help control plant diseases. It generally does not increase soil erosion. Intense fire causes loss of large amounts of nitrogen and other essential nutrients, destroys organic matter, may break down soil structure and may induce water repellency. The soil may become eroded and lose some of its productivity potential. The frequency, timing, and intensity of burning and the kind of management practices after the fires influence the long-term effect of fire on soils (Tiedemann and others 1979).

Herbicides are widely used in the northeastern conifer region to reduce plant competition during conifer stand establishment. Young trees grow faster when competition for nutrients and water is reduced. About half the site preparation work in the Michigan-Wisconsin-Minnesota area is done with herbicides (Sajdak 1982). Movement of mobile herbicides like hexazinone and picloram has been evaluated in some areas (Neary and others 1985b). Although they pose little, if any, risk to most nontarget species because toxicities are low and they readily biodegrade, many gaps exist in the data on the fate and biological impact of these and other herbicides in the northeastern conifer forest. Unless there is a direct spill of concentrates into water, they have little off-site effect on surface water quality, riparian vegetation, or aquatic organisms (Ohmann and others 1978).

Eastern Hardwoods

Water Yield--For the purposes of the following analysis, the eastern hardwood region is considered to encompass hardwood types within the Appalachian Highlands physiographic division, which extends from Maine to northern Georgia. From a watershed management perspective, this region has received intensive investigation for many years.

In many fully developed hardwood forests, about 50 percent of the precipitation that falls is evaporated back to the atmosphere via processes shown in figure 1, and the other 50 percent contributes to streamflow or ground water. The primary effects of forest cutting, or any other reduction in live canopy, are reductions in transpiration and interception, with the consequences of greater availability of soil water for remaining plants or for streamflow and ground water. Of the standard harvest and regeneration methods for hardwoods, clearcutting produces the maximum reduction in evapotranspiration and thus the largest increase in streamflow. From experiments involving a variety of cutting intensities in eastern hardwood stands, a generalized response of first-year streamflow increases after cutting is available (fig. 4)(Douglass and Swank 1975). The first-year increase is proportional to the reduction in forest basal area and is also related to the energy available for evapotranspiration (insolation index). For example, clearcutting a north-facing (0.22 index) hardwood stand increases streamflow about 41 cm (16 in), while selection cutting in the same stand (30-percent reduction in basal area) increases flow about 8 cm (3 in). These generalized relations apply to a major portion of the moist eastern hardwood region but some exceptions should be noted. The magnitude of response will be less than that depicted in figure 4 on shallow soils with low moisture storage capacity and in localities with normally low precipitation and streamflow. Another exception involves certain cutting configurations on shallow soils such as "leave strips" of streamside vegetation for protection or sequential strip clearcutting. The vegetation remaining from these cutting patterns partially utilizes the extra soil

water, and thus streamflow increases are less than the proportional relationship shown in figure 4.

Streamflow increases are usually the largest in the first year after cutting. In subsequent years, as vegetation regrows, streamflow returns toward baseline levels at a rate approximating a logarithmic decay curve (Swift and Swank 1981). The average duration of increases varies substantially but an average duration is commonly 6-10 years (Stone and others 1980).

Streamflow Timing--Annual water yield increases associated with cutting are not distributed uniformly throughout the year (Douglass and Swank 1972). In areas with shallow soils and a snow cover such as northern hardwood forests, a large proportion of increased flow occurs in the spring and summer months in direct response to precipitation patterns and reductions in evapotranspiration due to cutting. Flow is also increased in summer months when hardwoods are cut in the southern Appalachians, but a large proportion of evapotranspiration savings due to cutting appears as flow in the autumn months and can extend into early winter. A combination of deep soils and rainfall distribution is responsible for the lag between when evapotranspiration savings occur in the soil and when they appear in the stream.

Reduced evapotranspiration after cutting means less potential storage of soil water during storms. Thus, a greater proportion of the infiltrating rain appears as streamflow and contributes to peak flow rates and stormflow volumes. Differences in storm runoff between harvested and uncut areas are minimum when soils of both are fully recharged, as is frequently the case during the winter (Lull and Sopper 1966; Anderson and others 1976). Local and regional flooding are usually associated with extensive frontal storms or high-intensity thunderstorms; during these conditions of heavy rain, even forested soils are saturated and stormflow is similar for harvested and uncut areas. Thus, the influence of cutting on stormflow characteristics is most prevalent prior to recharge. In some locations of the eastern hardwood region, cutting causes more rapid snowmelt in the spring which produces elevated peak flow rates early in the melt season and decreases later in the season (Hornbeck 1973). Soil compaction associated with logging roads and skid trails reduces infiltration of precipitation and is a major cause of stormflow. The absence, or low density, of carefully constructed roads combined with little disturbance to the forest floor during harvest, produces increases of only about 10 percent in peak flow rates and stormflow volumes (Swank and others 1988). As the density of roads and skid trails increases, the flow of excess water toward streams is concentrated and may increase peaks and volumes of stormflow. The quality of road and skid trail layout is a key factor determining the relative impacts of harvesting on stormflow characteristics (Lull and Reinhart 1972).

Sedimentation--A major concern in harvest and regeneration practices is the impact on stream sedimentation. Natural geological erosion in the moist climate of forested lands in the hardwood region averages about 0.2 tonne/ha (0.1 ton/acre) annually (Patric 1980). The primary sources of additional sediment associated with silvicultural practices are roads and skid trails as documented in many studies (Lull and Reinhart 1972; Anderson and others 1976). Some temporary increases in stream turbidity are an inevitable consequence of any product removal but can be minimized by careful layout, construction, and maintenance of roads. The most critical aspect of road construction occurs at stream crossings since soil eroded from cuts and fills has direct access to the stream. A key factor in erosion control for roads is rapid establishment of surface protection such as a grass cover (Swift 1984a). Immediately after construction, the roadbed accounts for only 10-30 percent of the total soil loss from roads (Swift 1984b), but after cut and fill stabilization, the roadbed may be a major source of stream sediment, particularly with continual use. Thus, the type and amount of road surfacing are important factors in controlling soil loss (fig. 5).

Although the type of silvicultural method has little direct influence on sedimentation hazard, it does influence the amount of road in active use. For example, the length of road used to harvest the same annual volume from a forest tract under selection systems is greater than under heavier cutting systems. In general, effective procedures that minimize sediment from logging and road construction activities are well known (Kochenderfer 1970; Hewlett and Douglass 1968) and need only to be judiciously applied.

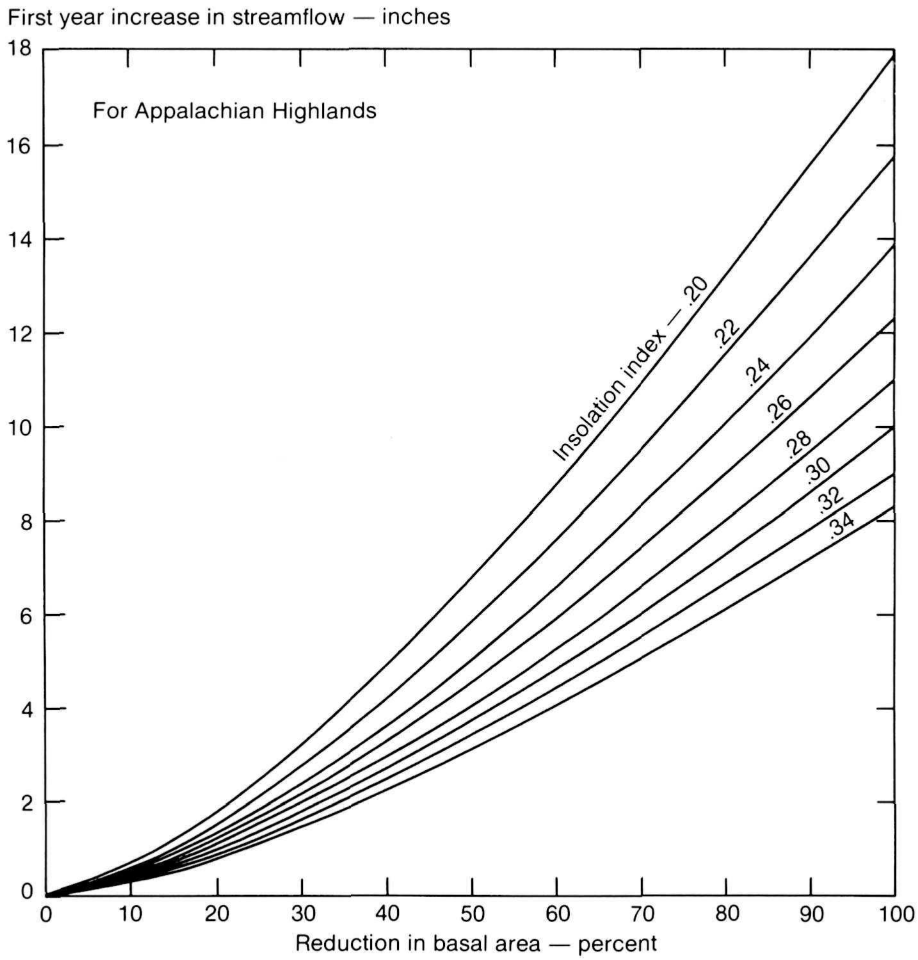

Figure 4--*Streamflow increases in the first year after cutting a hardwood forest are related to the amount of vegetation cut (expressed as basal area) and the amount of solar radiation received by the forest (expressed as insolation index). The threshold for any measurable stream increase occurs after about a 13 percent reduction in basal area (Douglass and Swank 1975).*

Stream Temperature--In the Appalachians, removal of the vegetative canopy adjacent to forest streams increases solar heating of waters with consequent increases in maximum summer temperatures of streams of from 1.1-6.1 °C (2-11 °F)(Swift and Messer 1971; Hornbeck and Federer 1975; Kochenderfer and Aubertin 1975). The larger additive temperatures can elevate maximum temperatures above the upper limit acceptable for some cold water fish. This response is of most concern when large clearcuts extend to the stream. However, watershed studies have shown that adverse increases in stream temperature can be avoided by maintaining a "leave strip" of vegetation along the live stream channel (Hornbeck and others 1986b). Moreover, stream water at an elevated temperature rapidly cools to near ambient levels as it enters shaded downstream reaches and cooler ground water flows into it. As Stone and others (1980) observed, elevated stream temperature need not be regarded as an inevitable consequence of harvest method but is subject to tradeoff analysis in forest planning.

Dissolved Nutrient Losses--Forest cutting and harvest interrupts the natural recycling of nutrients as well as water. One concern is that nutrients released from harvested areas may adversely affect downstream values and uses. During the past decade, an abundance of new information for eastern hardwood forests has appeared on this topic, particularly for clearcut harvesting that produces the maximum

response in stream chemistry. Changes in stream water nutrient concentrations following clearcutting varies substantially between localities. In central and southern Appalachian forests, measurable increases in concentrations of dissolved forms of nitrogen, calcium, potassium, and several other constituents have been observed following clearcutting (Aubertin and Patric 1974; Swank l986), but the magnitude of changes is small and unimportant with regard to downstream uses. In contrast, large increases in concentrations of some nutrients accompany commercial clearcutting in northern hardwoods of New Hampshire (Martin and Pierce 1980; Hornbeck and others 1986a). Reasons for these different geographic responses are not entirely clear, but are partly attributed to high organic matter and nitrogen in the forest floor of northern hardwoods (Stone and others 1980). Clearcutting increases moisture and temperature, which enhance decomposition and nitrogen transformations of the litter layer with subsequent nutrient release. Similar responses could be expected in other locations with comparable forest floors and climatic conditions conducive to decomposition and leaching.

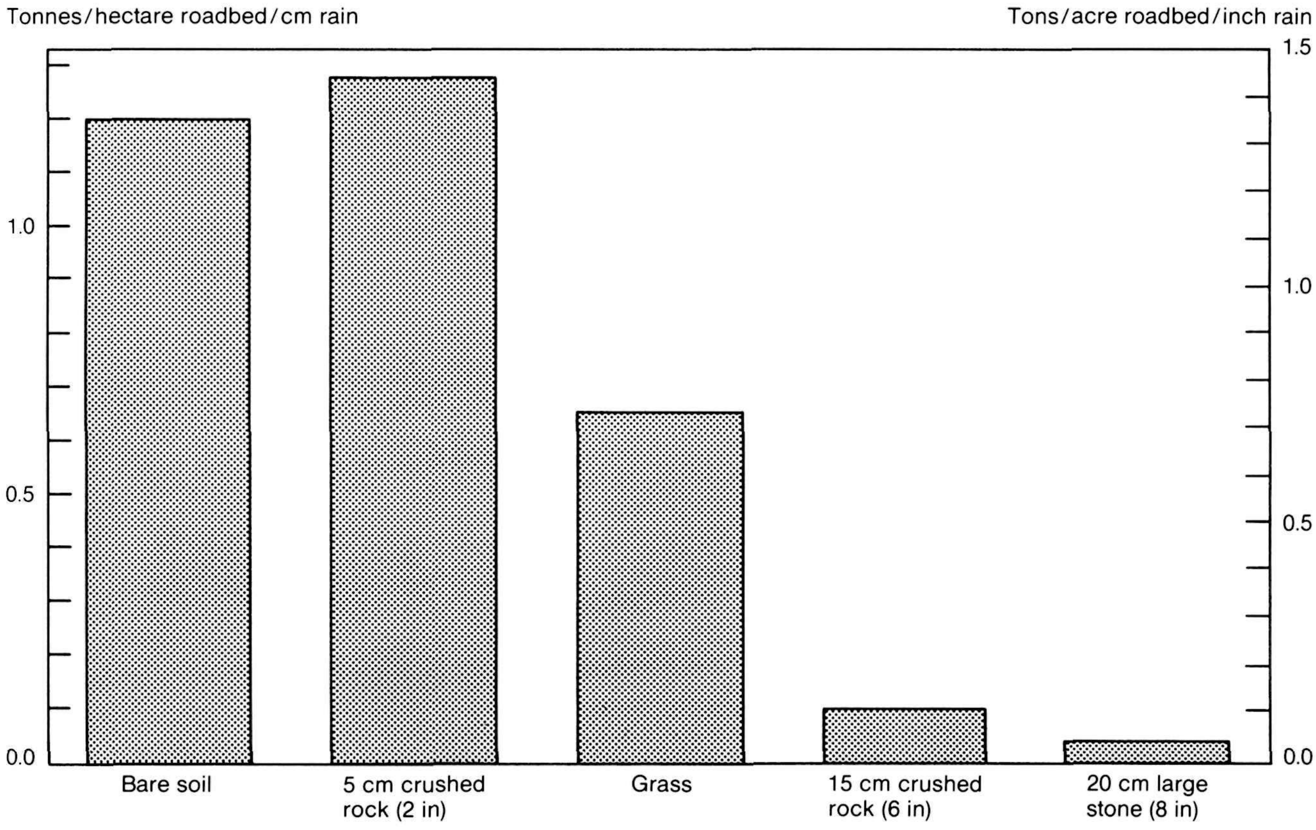

Figure 5--*Mean soil loss rates for five logging road surfaces constructed on sandy loam soil in western North Carolina. Data are based on 30 storms during autumn and winter periods with light vehicular use (Swift 1984a).*

The recovery of stream nutrient concentrations is nutrient- and site-specific but tends to follow the time trend of streamflow recovery, that is, a return to baseline levels in 5-10 years. Most headwater streams draining forested land in the East are low in dissolved nutrients and even large increases in nutrient concentrations are of little concern with regard to most downstream uses. Biologists agree that some increase in dissolved constituents of these streams offers potential benefits to the biota and stream productivity.

Although concentration changes may be small, the increase in total nutrient export must be considered,

simply due to the greater stream discharge after cutting (discussed in a previous section). For example, after a southern Appalachian hardwood forest was clearcut and logged, average concentrations of potassium and calcium in the stream increased only 10-20 percent. However, when combined with annual increases in discharge, export of these nutrients from the soil increased by 30-40 percent (table 1). As discussed in the following section, these accelerated nutrient losses may be more critical to soil fertility than water quality.

Table 1--*Increases in calcium and potassium exported in stream water during the first 3 years after commercial clearcutting a hardwood forest in the southern Appalachians. Values are derived from the difference between measured export for the year and the export expected if the forest had not been cut (Swank 1986)*

	Increase in export of:	
	Ca	K
Year after cutting	*pounds/acre/year (percent)*	
1	2.6 (32)	2.0 (40)
2	2.5 (30)	2.0 (40)
3	3.2 (30)	2.4 (43)

Soil and Soil Nutrients--Harvest and regeneration practices alter a variety of biological, physical, and chemical processes in the soil, and the integrated effects of these alterations are partly reflected in water quality responses previously discussed. However, some effects on soils are not entirely expressed in stream water. For example, nutrient removal from a site in harvested wood carries the risk of soil nutrient depletion for the next crop. Evaluation of impacts on soil productivity are especially complex because assessments are site specific and involve a wide range of soil-vegetation types and rates of nutrient replacement from the atmosphere and from soil weathering. Regeneration methods such as selection cutting remove lesser amounts of nutrients than more intensive methods such as clearcutting. Furthermore, studies in eastern hardwoods indicate that conventional clearcut harvest with only sawlog removal is usually not a serious threat to soil nutrient depletion (West and Mann 1983, Patric and Smith 1975). For example, quantities of nitrogen, calcium, and potassium deposited annually in precipitation are sufficient to replace annual nutrient removal in sawlogs assuming losses are distributed equally over the life of the stand (table 2).

Of more concern is nutrient depletion associated with intensified forest management practices such as reducing the period of time between harvests and increased wood fiber utilization for firewood, pulpwood, and chips. Practices that remove all stems as well as branches, twigs, and foliage remove proportionally more nutrients than stem harvest only since these tree components are higher in elemental content. With whole-tree harvesting, removal of nitrogen, phosphorus, potassium, and calcium are about threefold greater than sawlog harvesting (Johnson and others 1982). Analyses suggest that such practices may reduce soil fertility and hardwood productivity (Swank and Waide 1980; Ranscher and others 1983; Johnson and others 1982; West and Mann 1983). Substantial additional research is needed to more fully predict the consequences of increased fiber removal on productivity (Ballard and Gessel 1983).

Table 2--*Annual inputs of Ca, K, and N in precipitation and annual rates of removal associated with clearcut sawlog harvest for two hardwood stands and harvest cycles (Swank 1984)*

	Nutrient		
	Ca	K	N
Management alternative		*pounds/acre/year*	
Precipitation input	4.8	2.1	8.8
Yellow-poplar sawlog removal (50-year harvest cycle)	3.8	1.2	2.5
Mixed hardwood sawlog removal (90-year harvest cycle)	4.3	1.3	2.1

In the past decade, the use of herbicides and fire as site preparation tools has increased in eastern hardwoods. The primary concern about the use of herbicides as a silvicultural tool is contamination of surface and ground waters. Studies in southern Appalachian hardwoods using picloram and hexazinone showed that with careful application, herbicide levels were not of sufficient magnitude or duration to impact aquatic species and were well below suggested water quality standards (Neary and others 1985a, 1986). However, many gaps still exist in our knowledge of the fate of herbicides in forests. Extensive research is needed as new forest herbicides are registered and methods of application change. Efforts should focus not only on potential impacts on water but also assessments of biological impacts such as effects on soil flora and fauna. Fire is increasingly being used where hardwoods have been harvested and the residue is then burned and the site is planted to pine. Recent research indicates that when conducted under proper fuel and weather conditions, high-intensity fires do not result in increased erosion (Danielovich 1986). However, much remains to be learned about the effects of this practice on soil and water resources and research is urgently needed within the eastern hardwood region.

Southern Conifers

Water Yield--Coniferous stands occupy 41.3 million hectares (102 million acres), or 34 percent of the forest land east of the Mississippi. Water yield equations of the type available for eastern hardwoods are lacking for conifers; therefore, the quantitative effects of different silvicultural prescriptions on streamflow are not well known for all species of southern pine. However, as a general principle, evapotranspiration from conifers in the southeast is greater than from hardwoods for the same climatic conditions (Swank and Douglass 1974). Retention of foliage year round and high leaf area of conifers contribute to both greater interception and transpiration from pine compared to hardwoods. Interception alone was estimated to account for 8-10 cm (3-4 in) difference in yield between pine and hardwoods in the South Carolina Piedmont and Coastal Plain (Swank 1968). Because of greater evapotranspiration by pine, conversion of hardwood stands to pine would be expected to reduce water yield. However, since pines are sometimes more intensively managed (shorter rotations and more frequent thinnings) than hardwoods, water yield from pine stands may be similar to that from hardwoods over long periods of time (Van Lear and Douglass 1982).

Based on accumulated experience from various experiments, Douglass (1983) proposed equations for predicting annual water yield responses to cutting of pine; however, the performance of the equations is untested. Experimental results indicate that clearcutting loblolly pine increases first year water yields by 25-46 cm (10-18 in)(Anderson and others 1976; Hewlett 1979), while water yield may more than double following clearcutting and site preparation of slash pine in the flatwoods of Florida (Riekerk 1983b). In flat terrain such as the lower Coastal Plain, the response to cutting is frequently a rise in the water table (Williams and Lipscomb 1981).

Streamflow Timing--In upland streams draining pine-covered land, about 20 percent of the total streamflow is stormflow and 80 percent is baseflow (Van Lear and Douglass 1982). Harvesting in southern pine is frequently followed by site preparation practices including a variety of mechanical treatments, burning, or application of herbicides. These practices may increase the potential for storm runoff and sediment production if the protective forest floor is disturbed and the surface soil is compacted.

Following clearcutting loblolly pine on small (less than 2 ha [5 acre]) watersheds in the Piedmont of South Carolina, total stormflow volumes increased up to 100 percent and peak flows of average storms increased 55-150 percent (Douglass and Van Lear 1983). Clearcutting shortleaf pine (*Pinus echinata*) followed by several different mechanical site preparation treatments in east Texas increased mean stormflow by threefold to sixfold the first year after harvest (Blackburn and others 1986). Four years after disturbance, stormflow was still significantly elevated above undisturbed watersheds. In a long-term study in northern Mississippi, Ursic (1985) showed that stormflow volumes for pine catchments, formerly in depleted hardwoods, were decreased an average of 83 percent by plantation age 12. After clearcutting of pine plantations, stormflow volumes returned to or exceeded preplanting levels. Harvesting and site preparation in Florida slash pine (*Pinus elliottii*) flatwoods have also been shown to substantially increase stormflow volumes (Swindel and others 1982). Generally, pine silvicultural operations increase stormflow but the magnitude of responses varies greatly depending upon specific cultural practices and soil conditions such as storage capacity and channel characteristics.

Erosion and Sedimentation--A baseline value of about 60 mg/l (60 parts per million [p/m]) has been suggested as the average annual sediment concentration in stormflow from small, pine-covered watersheds in the South (Ursic 1979). A more recent review of background-level data for all pine types by Ursic (1986) indicates an average annual sediment concentration of 0.006 tonne per hectare-centimeter (0.007 ton per acre-inch) of flow. Much of the sediment comes from erosion of the minor channels developed during former land uses; therefore, natural sedimentation rates may vary substantially depending upon channel characteristics. The increases in stormflow from harvesting and site preparation accelerate the rates of baseline sediment losses to varying degrees depending on the nature of the disturbance, characteristics of the soil, and climatic factors. Increases in sediment concentrations are greatest for those practices that expose a high proportion of mineral soil (Ursic and Douglass 1979). For example, the practice of shearing and windrowing generally exposes more soil and produces higher sediment losses than roller chopping (Blackburn and others 1986). Average annual sediment concentrations associated with shearing and windrowing frequently exceed 2500 mg/l (2,500 p/m) with sediment losses of more than 2000 kg/ha (1,784 lbs/acre)(Beasley 1979; Douglass and Goodwin 1980; Blackburn and others 1986). The duration of elevated sediment losses is related to how rapidly vegetation becomes reestablished. Some studies indicate that sediment losses return near preharvest levels within a 4-5-year period after disturbance. The importance of cover in controlling soil loss is illustrated in figure 6. Data were derived from 16 small watersheds receiving a variety of mechanical site preparation treatments in the Piedmont of North Carolina. Percent ground cover accounted for 89 percent of the variation in soil loss, and as values dropped below 40 percent, soil loss increased sharply regardless of treatment method.

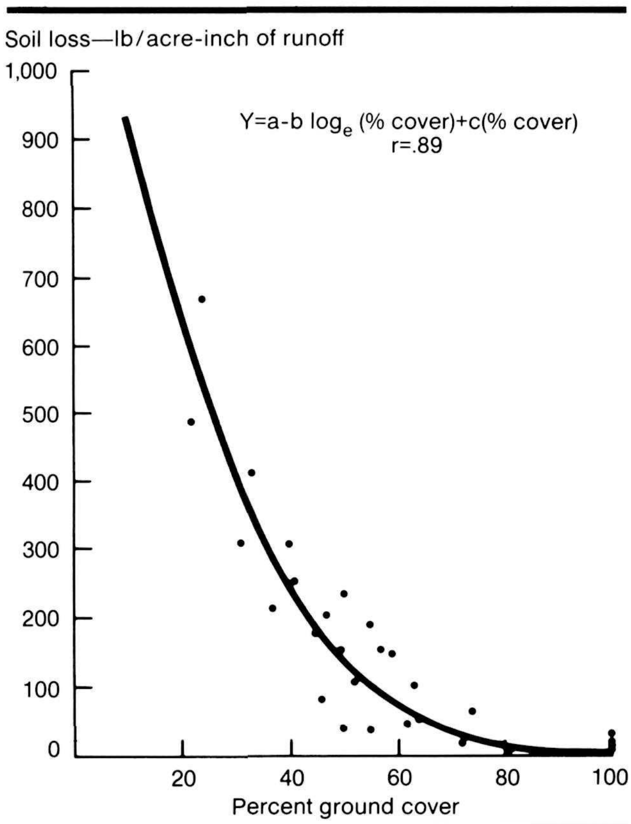

Figure 6--*Soil loss in pounds per acre-inch of runoff depends almost entirely on the amount of ground cover present to protect the soil from splash erosion (Douglass and Goodwin 1980).*

Soil and Soil Nutrients--Prescribed fire is commonly used throughout the southern pine region for a variety of purposes. The impacts of prescribed fire on soil and water have been most intensively studied in the Coastal Plain, with much less information available for the Piedmont region. Effects depend on numerous factors including soil moisture, vegetation type, fire intensity and frequency, and temperature (Wells and others 1979). Long-term studies indicate that frequent, low-intensity fires may enhance forest productivity by releasing phosphorus and other nutrients (McKee 1982). In a review of prescribed burning studies in the South, Van Lear (1985) emphasized the importance of the quantity of forest floor and residual debris consumed by fire as a primary factor affecting soil nutrition. In general, low-intensity fire has little or no adverse impact on soils, and even high-intensity prescribed fires have only a temporary negative effect on soil nutrients. The effects of high-intensity fires that may occur in site preparation burns are not known and require research.

In the past 5 years, herbicide use in southern pine silviculture has increased dramatically. Lower site preparation costs, better pine survival, and faster stand growth have resulted from effective chemical weed control (Pywell and others 1985). Recent studies of hexazinone, picloram, 2,4-D, imazapyr, and sulfometuron methyl indicate that proper herbicide use should not adversely impact nontarget organisms or surface water quality (Neary 1985). Extensive research is still needed to evaluate biological impacts, potential for groundwater contamination, the hazards of new silvicultural chemicals, and the usefulness of pesticide movement simulation models. Herbicide use in southern pine forestry is reducing adverse soil disturbance produced by mechanical site preparation (Neary and others 1984). However, herbicides are sometimes used in combination with fire when preparing sites because herbicides alone do little to reduce the logging debris that hinders planting.

As in other forest types, the potential effect of whole-tree harvesting of southern pines on soils is site specific. In general, nutrients removed in biomass exceed leaching losses in the Piedmont and Coastal Plain regions. The impact of more complete nutrient removals and/or shorter rotations on productivity has not been quantitatively demonstrated in the South. However, studies that have evaluated nutrient removals in the context of soil nutrient pools and recycling processes suggest that more intensive harvest could deplete soil nutrients and reduce productivity (Van Lear and others 1983; Riekerk 1983a; Williams and others 1983). Whole-tree harvesting markedly increases the quantity of nutrients removed from the site as compared to conventional harvesting. However, whole-tree harvesting eliminates the need for intensive mechanical site preparation, which helps conserve nutrients. Morris and others (1983) showed that raking debris and litter into windrows removes greater quantities of nutrients from sites than whole-tree harvesting. Additional research and further development of predictive methods are needed to address this complex problem.

Nutrient Losses--Concentrations of dissolved nutrients show little change following both prescribed burning and commercial clearcutting in loblolly pine stands (Douglass and Van Lear 1983; Van Lear and others 1985; Ursic 1985). Where elevated concentra-

tions are observed, there is little concern about water quality degradation because of the low baseline levels of dissolved nutrients in streams draining pine stands (Van Lear and Douglass 1982). However, harvesting increases runoff and consequently total nutrient export, which could be important to onsite nutrition (Van Lear and others 1985).

Of greater significance are nutrient exports transported by sediments. Duffy and others (1986) found that more than 40 percent of the N and 70 percent of the P in stormflow were transported by sediment following harvesting on small catchments of pine. Activities such as harvesting in combination with site preparation, which substantially increases erosion and sediment export, could have an adverse impact on site productivity.

Summary

Quantification of the impacts of silvicultural practices on soil and water is not possible across the wide range of forest types and regions considered in this paper. However, research has provided a scientific basis of general principles that indicate the relative magnitude of changes to expect. In this context we present the following generalizations of broad responses of soil and stream parameters to the array of harvest, regeneration, and other cultural practices.

1. Clearcutting produces the maximum increases in streamflow or ground water, and as cutting intensities decrease, such as in shelterwood and selection cutting, less extra water is produced. For a given cutting practice, the smallest increases tend to occur in drier climates. Within a climatic zone, larger increases could be expected from cutting conifer forests than from deciduous forests.

2. As vegetation regrows, streamflow or ground water recover toward precutting levels at a rate depending on how fast the vegetation recovers. In many regions of the country, recovery is usually complete within 10 years.

3. Forest cutting practices alter the timing of streamflow, usually by increasing discharge during the low flow period. The magnitude of stormflow increases depends on the amount of compaction. Adverse impacts can usually be avoided through proper logging road location and construction and/or harvesting methods appropriate for the terrain.

4. Natural geologic erosion is quite low from most forested lands. Roads and skid trails are the primary sources of additional sediment associated with harvesting practices. Effective procedures and methods are available for some regions of the country that minimize sediment from harvesting practices, and most management goals can be achieved by following the "best management practices" concept.

5. Harvesting interrupts the natural cycles of nutrients and, as with water yield, the greatest changes occur with clearcutting. Nutrient concentration increases are typically greater in soil solution than in streams draining harvested areas. Nutrient flushes to streams are usually short lived and rarely affect the use and quality of downstream water. The impacts of accelerated nutrient export on site productivity must be evaluated in the context of site-specific characteristics.

6. Harvesting trees adjacent to stream channels increases water temperatures and removes the buffering effects of streamside vegetation to overland flow and sediment delivery to the streams. Providing buffer strips at 15-30 m (50-100 ft) on either side of the stream can mitigate these effects.

7. Intensive management practices associated with silvicultural methods can have a significant impact on soil and water characteristics. Mechanical site preparation methods that expose large amounts of mineral soil also produce large, elevated soil losses that can have deleterious impacts both on- and off-site. Percent cover is the single most important variable controlling the magnitude and duration of soil loss from intensive practices.

8. Low-intensity fires used in prescribed burning may enhance forest productivity by releasing nutrients important to tree growth.

The effects of high-intensity fires used in site preparation are not well known but could potentially have adverse impacts on soil productivity.

9. The effects of whole-tree harvesting on soil and water vary widely and appear to be site specific. Generally, there is concern that shorter rotations and/or complete utilization of wood fiber may reduce soil fertility and forest productivity. Improved methodology is needed to better predict and evaluate the consequences of increased fiber removal on productivity.

10. Most evidence of herbicide use on forest land shows that if prescribed procedures are followed and buffer strips are maintained around streams, there should be little adverse impact on surface water quality. Information is incomplete to evaluate biological impacts, ground water contamination, and hazards of new chemicals used in silvicultural operations.

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Effects of Timber Management Practices on Forest Wildlife Management

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This paper draws heavily, in some cases verbatim, from summaries by Gill and others 1976, Thomas and others 1975 and 1976, and Thomas 1979.

Introduction

Until just a few years ago, forest managers were not especially concerned with wildlife. The law did not require it. The public did not demand it. Politics did not compel it. Public forest lands in the West were still largely an untapped source of wood products and recreational space for the growing Nation. Forest lands in the East were still recovering from the logging boom at the turn of the century. Many resource management professionals were secure in the assurance given them in their basic forestry and wildlife management classes that "good timber management is good wildlife management."

Times have changed. Laws have changed. Public demands and politics have changed. Lands in the East have been reforested. Public forests have been thrust into the forefront as a prime supplier of wood products and recreation. It seems likely that these forests will become ever more intensively managed to meet the Nation's burgeoning demands for wood, water, recreation, grazing, and wildlife and fish. As for good timber management being good wildlife management, wildlife biologists and foresters alike have found that it is not necessarily so!

Forest managers are now under increasing pressure to account for wildlife in their management activities, particularly land-use planning. That means all wildlife--not just species that are hunted or are esthetically pleasing or classified as threatened or endangered.

In the past, wildlife management in forests has been considered from a rather limited viewpoint. The standard practice has been to study one species at a time or develop management plans for one species or a limited number of species. As a result, wildlife biologists and foresters have been unable to effectively evaluate the impacts of forest management on all wildlife.

So we begin here with a different approach and a simple question. What do forest managers do that affects wildlife? They certainly do not manage wildlife directly. They manage habitat. The forest manager alters wildlife habitat with every decision. Habitat is something the forest manager can relate to, understand, and control. Most important, it is an entity for which a manager can be held accountable. The maintenance of appropriate habitat is the foundation of all wildlife management. Habitat, therefore, is the key to organizing knowledge about wildlife so it can be used in forest management.

The Nation's forests are one of the last remaining natural habitats for terrestrial wildlife. Much of this vast forest resource has changed dramatically in the last 200 years and can no longer be considered wild. It is now managed for multiple-use benefits, including timber production. Timber harvesting and roadbuilding now alter wildlife habitat more than any other management activity.

Timber management and wildlife habitat management are seen as generally compatible, but only if the

needs of wildlife are recognized and considered along with requirements for timber management. This compatibility can be realized through a better understanding of plant and animal communities, how they change over time, and how they respond to silvicultural practices.

Management of wildlife on public lands is a joint responsibility of State and Federal Governments. By long standing agreement, the manipulation of wildlife populations or regulation of the harvest of wildlife on federally owned land is the prerogative of the States. Habitat management is the responsibility of the Federal land management agencies. Therefore, close cooperation is required between State and Federal agencies in setting and achieving wildlife management goals.

Wildlife as a Product of Forest Management

Forest management is the process of manipulating the forest environment to produce a mix of products desired by the owners. These products change with time, economic conditions, public demand, legislation, and capability of the land. Managers of federally administered lands have guidance, in the form of laws passed by Congress, as to what these products shall be. Other regulations result from agency and court intrepretations of these laws. A number of laws specify that wildlife shall be a product of Federal lands and that wildlife shall be considered in every management decision. Managers of State-owned lands and private landowners are influenced by similar State laws. In most managed forests, wildlife habitat is considered a byproduct of timber management. As demands have grown for increased production of wood fiber, recreation, and livestock, as well as for increased allocation for wilderness, it has become increasingly obvious that such cliches as "good timber management is good wildlife management" will no longer suffice (Bunnell 1976). Passage of the National Environmental Policy Act of 1969 (U.S. Laws, Statutes, etc., Public Law 91-190) and the Endangered Species Act (PL 93-205) brought matters to a critical stage. They require that the environmental effects of any federally financed project must be fully evaluated.

The Need

How is the forest manager to balance the demands for forest resources, including wildlife, and still maintain a sustained yield of wood products? How can the needs of all wildlife be considered? As these problems are pondered, the forest manager is likely to discover the wisdom of two of Commoner's (1971) "laws" of ecology, "everything is connected to everything else" and "there is no such thing as a free lunch." Forest managers must not be solely timber managers. They must take a more holistic view.

A Basic Assumption

The basic assumption about wildlife habitat management in forests that are managed under the policy of multiple use is that it must be carried out in coordination with timber management. Timber management is commonly the dominant vegetative management activity on large ownerships. Large-scale wildlife management usually results from the manipulation of forest vegetation primarily for wood production. Timber management **is** wildlife management. The degree to which it is **good** wildlife management depends on how well the wildlife biologist can explain the relationship of wildlife to habitat and how well the forester can manipulate habitat to achieve wildlife goals. These interrelationships are shown in figure 1.

Wildlife habitat management in forests often requires manipulation of tree cover (Trippensee 1948), but this is usually too expensive if done solely for wildlife purposes. Forest management practices undertaken to enhance wood production, however, cause dramatic changes in wildlife habitat. If correctly planned and executed, timber management practices are potentially the most practical way to achieve wildlife habitat goals. Where timber is not harvested, such as in wilderness areas or "old growth" set aside to meet the habitat requirement of species associated with mature forests, natural changes occur to the habitat. They may not be as noticeable, but these areas, and their wildlife, are continually changing.

In most situations, the wildlife biologist is responsible for making the forest manager aware of the ramifications of proposed forest management activities on wildlife habitats.

Large-scale wildlife goals must be accomplished through timber management

because

timber management:

- affects many acres
- is well financed
- dramatically affects wildlife habitat
- has great impact on wildlife

while

wildlife habitat management:

- affects few acres
- has little financing
- has little influence on wildlife habitat
- has little present impact on wildlife.

Figure 1--*Large-scale wildlife habitat management must be accomplished through timber management* (*after Thomas 1979:16*).

The forest manager considers advice from many staff specialists and selects a course of action. But it is the field forester who actually manipulates the vegetation and alters habitat. It is essential, therefore, that the forest manager, field forester, and wildlife biologist work closely together to achieve mutual objectives. Giles (1962:406) said, "The time has come to face up to the fact that the harvest of wood, a forester's function, has greater influence on game [wildlife] than any active technique available to the wildlifer. In one sale a forester can...influence more cover over a longer time than a game [wildlife] manager...can create...in a decade. The wildlifer, realizing the potentials of the wood harvest, must not only increase the effectiveness of his present practices, but must provide guidance for foresters so their efforts will not so strongly negate his efforts and can be made to complement them."

Principles of Forest-Wildlife Management

Resource management professionals come from varied backgrounds: forestry, ecology, wildlife biology, forest engineering, and landscape architecture, to name a few. For these professionals to work together, they need a common vocabulary and an understanding of the principles of forestry, ecology, and wildlife management. The relationship between terms used in forest and wildlife habitat management is shown in figure 2. These have been touched upon by such authors as Gill and others (1976), Hylander (1966), Leopold (1933), Odum (1963), and Thomas and others (1975, 1976).

Animal habitat is the arrangement of food, cover, and water required to meet the biological needs of one or more individuals of a species. Each species is adapted to a **habitat niche** or specific arrangement and amount of food, cover, and water. The role a particular wildlife species plays in the environment is referred to as its **ecological niche**.

Habitat capability is the inherent capacity of the land to produce food, cover, and water, either naturally or under intensive management.

A **plant community type** is a unique combination of plants that occurs in particular locations under certain environmental influences. The plant community type reflects the environmental influences on the site, such as soil, temperature, elevation, solar radiation, slope, aspect, and rainfall, as they influence vegetation (Daubenmire 1976).

Plant communities are defined in terms of the dominant single species of climax vegetation. The plant community evolves through a general series of conditions as it progresses from bare ground to final **climax** stage. This process is called **succession** and the various stages are known as **successional stages**.

Each combination of plant community and successional stage has its own unique set of habitat niches. The wildlife supported by these habitat niches make up the attendant **animal community**. The animals fill various ecological niches and, in turn, influence the plant community. Habitat niches are valuable to wildlife for feeding, reproduction, or security. Individual species may use a particular habitat on a seasonal or yearlong basis. See also reviews by Meslow and Wight (1975) and Thomas and others (1975).

Some of the terms already discussed have counterpart terms that are used primarily in forestry. It is important to understand their relationship to the language of ecology and wildlife biology.

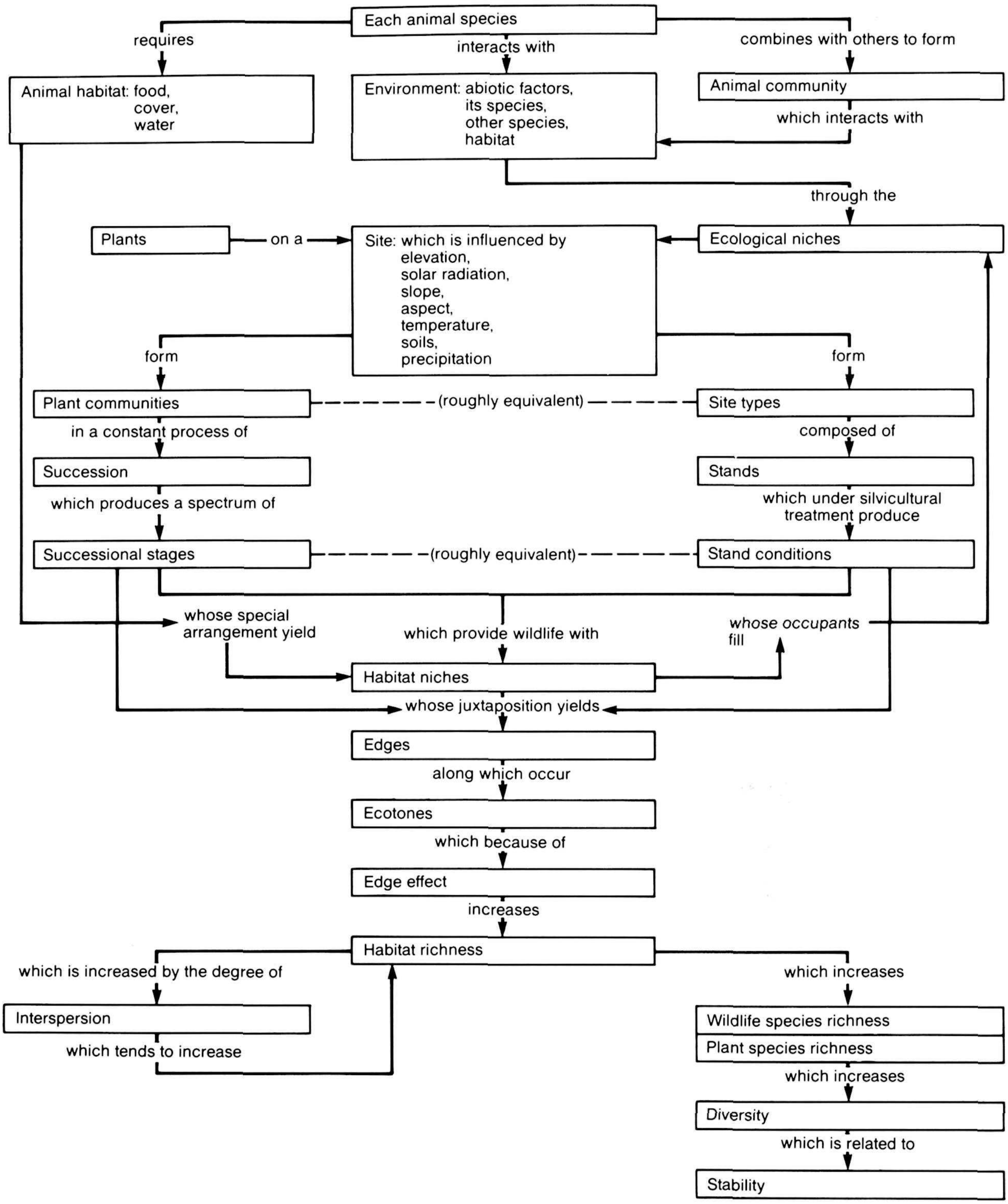

Figure 2--*Relationship between terms used in forest and wildlife habitat management* (after Thomas 1979:14).

A **site** is an area considered in terms of its environment, particularly as this determines the type and quality of the vegetation the area can support. Sites are classified either qualitatively by their climate, soil, and vegetation into **site types** or quantitatively by their potential for producing wood into **site classes** (Ford-Robertson 1971). Site type is roughly analogous to the plant community.

Each site is occupied by one or more **stands**. They are plant communities, particularly trees, that have sufficient uniformity of composition, size, density, age, spatial arrangement, and condition to distinguish them from adjacent plant communities. Stands are the common basis on which silvicultural prescriptions are considered (USDA Forest Service 1974). The **stand condition** can be described by measuring these factors. Timber harvest or other silvicultural treatment alters stand condition. Stand condition is roughly analogous to successional stage, when wildlife habitat is considered, because both measure the composition and structure of the stand.

The juxtapostion of plant communities, successional stages, or stand conditions within communities produces **edge**. The area where the two communities or successional stages overlap or produce a distinct combination of plants or structure is called the **ecotone**. Edges and their ecotones are rich habitat for wildlife because they have attributes of the edge itself plus those of the adjoining communities or successional stages (Leopold 1933). The influence of this phenomenon on animal populations is called **edge effect.**

Increasing the amount of edge increases **habitat richness**, which is a measure of the number of wildlife species resident within an area. The mixing of plant communities or successional stages is measured by the degree of **interspersion.** An increase in interspersion increases the amount of edge. In turn, this may increase the **diversity** that exists in plant and animal communities (Patton 1975). Increased diversity in plant communities provides an increasing number of habitat niches which, in turn, support more animal species. A forest with a high degree of diversity of communities and successional stages provides habitat for a wide variety of wildlife (Odum 1971). However, without some qualification on stand size, habitat may become fragmented and too small to maintain some species. Some plant and animal species require a minimum size to maintain their integrity.

Increased diversity is thought by some ecologists to be related to community **stability**. Stability is the ability of a community to withstand catastrophe (Margalef 1969) or to return to its original state after severe alteration. Such a cause-and-effect is suspected but has not been proved (Odum 1971:256).

> "If it can be shown that biotic diversity does indeed enhance physical stability in the ecosystem, or is the result of it, then we would have an important guide for conservation practice." "...is variety only the spice of life or is it a necessity for the long life of the total ecosystem comprising man and nature?"

A **forest ecosystem** is a complex of plant and animal communities along with the abiotic environment that comprises one functioning whole. Forest ecosystems are dynamic. Any change in forest structure or composition will favor some wildlife species while adversely affecting others. Such changes can affect the number and type of wildlife species and their use of habitat.

Forest-Wildlife Management Systems

Wildlife management is the scientifically based art of manipulating habitat to enhance conditions for a selected species or manipulating animal populations to achieve other desired ends (fig. 3). The term "wildlife management" implies the ability and managerial flexibility to manipulate vegetation (habitat) or animal populations or both (Leopold 1933; Trippensee 1948; Giles 1971).

There are two general production goals in wildlife management--management for habitat diversity for species richness (Evans 1974; USDA Forest Service 1973, 1975) and featured-species management (Zeedyk and Hazel 1974; USDA Forest Service 1971)(fig. 4).

The goal of management for habitat diversity to achieve species richness is to ensure that most wildlife species are maintained as residents of the managed forest in viable numbers (King 1966). Hence, all species are important. Management for species richness can be achieved by providing a broad spectrum of habitat conditions; characteristic stages of adequate size of each plant community should be represented in the vegetative mosaic. To do this, it is necessary to have information on the habitat needs

of each species and to know the various species associated with the various plant communities. This must then be incorporated into guides to protect the integrity, stability, and diversity of the forest ecosystem. The result should be a relatively stable and varied wildlife population.

Under featured-species management, the goal is to produce selected species in desired numbers in specific locations. This can be achieved by manipulating vegetation so the limiting factors of food, cover, and water are made less limiting for the species featured or by management actions such as restricting human access. These may be game species, threatened or endangered species, or species that have particular esthetic value.

Featured-species management has also been called key-species management or indicator-species management if the species selected represent the habitat needs of several species. If the species to be featured are carefully selected and their habitat needs vary widely, then featured-species management will also ensure habitat diversity. The result can be similar to management for species richness. The two management systems can also be used together to ensure species richness while favoring selected species in specific locations for particular purposes. For example, management for habitat diversity and species richness can be accomplished by providing an appropriate mix of successional stages or stand conditions within each plant community. Featured-species management can be accomplished by arranging stand size and successional stages to provide both cover and forage for selected species.

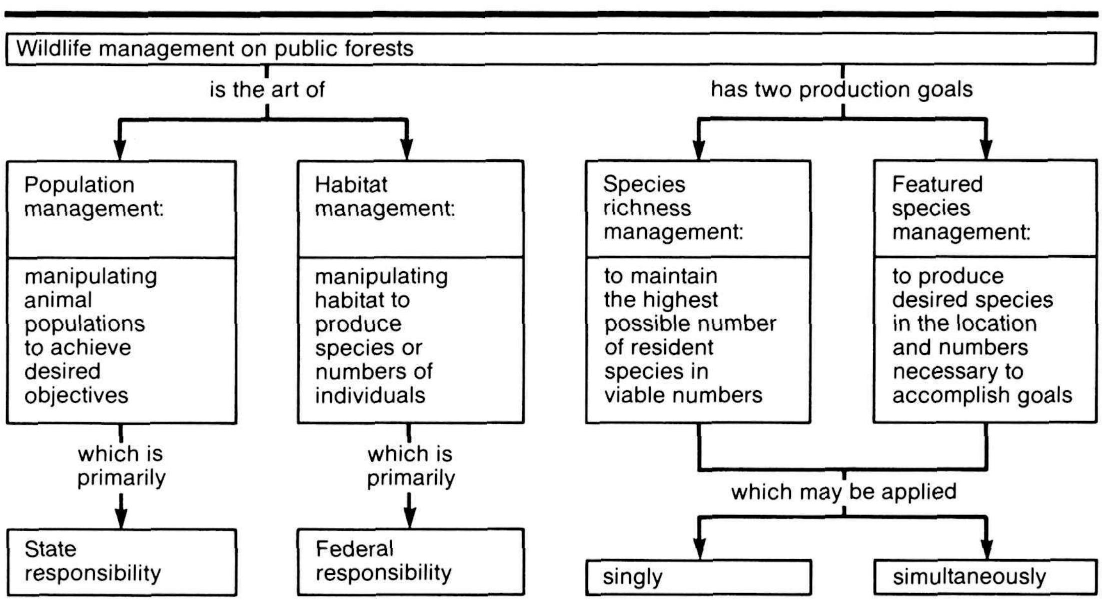

Figure 3--*The art and goals of wildlife management on forested lands* (after Thomas 1979:16).

Timber Management Systems

Different timber management systems have different potential to affect diversity and stability of the forest ecosystem because of their tendency to either magnify or reduce the dynamic aspects of plant community development. The two most commonly used systems are uneven-aged management and even-aged management or combinations or modifications of those systems (Twombly 1977; Work 1977).

Uneven-aged management maintains stands of trees that differ markedly in age (Ford-Robertson 1971). Such stands are "continuously or periodically regenerated, tended, and harvested with no real beginning or end" (Alexander and Edminster 1977:5). This management system tends, over time, to reduce the horizontal diversity of plants and animals in the forest. The resulting stands often have high structural (vertical) diversity because of the intermingling of different ages and sizes of trees. But there is a gradual reduction of shade-intolerant trees and understory

plants (Franklin 1976). Uneven-aged management tends to produce large blocks of continuous forest cover dominated by relatively mature trees. Such forests lack the variety of distinct successional stages that ensure diversity and a myriad of habitat niches.

Production goal	Management for species richness	Featured species management
Objective	Insure that all resident species exist in viable numbers. All species are important.	Produce selected species in desired numbers in designated locations. Production of selected species is of prime importance.
Process	Manipulate vegetation so that characteristic stages of each plant community are represented in the vegetative mosaic.	Manipulate vegetation so that limiting factors are made less limiting.

Figure 4--*Production goals in wildlife management* *(after Thomas 1979:16).*

Uneven-aged management, however, can be a useful wildlife management technique. It benefits wildlife and plant species adapted to more mature forest conditions, and it can be used to preserve the integrity of delicate and disproportionately important wildlife habitats, such as riparian zones.

Uneven-aged management involves harvest of timber by either single tree selection or group selection. Uneven-aged stands have a high degree of vertical diversity. They "...are distinctly irregular in height with great variation in size of trees. Competition between age classes is unequal; the smaller, younger trees tend to grow slowly because they are suppressed by the larger, older trees which grow quite rapidly" (Smith 1962:357). Conversely, the horizontal diversity between stands will be low in an ideal uneven-aged situation. When forests under uneven-aged management are examined carefully, it is obvious that the forest is composed of small groups of even-aged trees. The characteristics of horizontal diversity "...are most pronounced along the margins of the small even-aged groups that must inevitably make up most of an uneven-aged stand..." (Smith 1962:357).

In the group selection form of uneven-aged management, trees are cut in small groups rather than individually. If the openings created exceed 0.4 ha (1 acre), this will tend to produce conditions similar to even-aged management (U.S. Department of Agriculture 1973). Group selection tends to increase diversity of plants and animals because of temporary increases in shade-intolerant plants and forage plants in the small openings created. But such small openings do not satisfy the territorial requirements of many species adapted to early successional stages. Such species may not be present in such a forest even though various successional stages are present.

The objective of even-aged timber management is to maintain forest stands and produce crop stands with little or no difference in tree age. By convention, the age of trees in such stands can vary from 10 to 20 years for rotations of less than 100 years and as much as 30 percent of the rotation period for longer rotations (Ford-Robertson 1971). In the East, area control and composition objectives determine silvicultural treatments to achieve the desired future condition set forth in Forest Plans.

Even-aged management implies that even-aged stands of various ages and sizes are distributed throughout the managed forest. This is necessary to ensure a continous flow of wood products to the market. As a result, the potential for a mix of successional stages or stand conditions is present at all times. This should ensure a comparatively high degree of diversity of habitat niches and wildlife.

A forest under even-aged management usually has individual stands of relatively low vertical diversity because of the comparative simplicity of the stand structure. Smith (1962:357) said that even-aged stands tend to be of uniform height with a high degree of competition between trees of approximately the same size. The lower branches die and the trees have short, narrow crowns.

Most even-aged stands have a single-tiered canopy. This is not always true, however. Stands resulting from shelterwood and seed tree regeneration techniques or stands resulting from regeneration cuts where trees are left for wildlife objectives may be multitiered for many years after final harvest in a rotation because some trees are left to provide shade or seed. This adds vertical diversity and enables birds that would otherwise be eliminated during the early years of the rotation to use the stands. The effect may be temporary, however, if overstory trees are removed after the new stand is established. Trees left on some sites often succumb to windthrow, sunscald, insects, or disease.

The major difference between uneven-aged and even-aged management systems, in terms of habitat, is the long-lasting effect of the regeneration harvest. Even-aged systems--such as clearcutting, seed tree, or shelterwood harvest--produce distinct successional stages and a high degree of horizontal diversity because there are numerous stands of various age classes scattered through the forest. These stands provide a variety of habitats. For example, the vegetation associated with early successional stages provides forage for deer and elk and a myriad of habitat niches for other wildlife. These conditions are not available in the more mature forest. The mature stages provide hiding and thermal cover for deer and elk and for other wildlife species, such as the pileated woodpecker, that are adapted to mature forest habitats. The edges between stands form ecotones that provide additional habitat niches. The impact of regeneration cuts on wildlife have been reviewed by Hooven (1973), Pengelly (1972), and Resler (1972).

No single system of forest management can be a panacea for wildlife management. The decision about which system to use must be based on specific management goals. The forest structure must be considered, along with size and shape of the stand, its juxtaposition to other stands, the road systems, and special habitat needs. Flexibility in the use of silvicultural systems can be a key to meeting a range of wildlife goals. The appropriate uses of various silvicultural systems to achieve both timber and wildlife objectives is defined in Forest Plans developed under the National Forest Management Act of 1979. For examples, consider the discussion of silvicultural systems for ponderosa pine (Seidel 1973) and mixed conifer (Barrett 1973).

Every silvicultural decision has consequences for wildlife. Relationships between forest conditions and wildlife habitats have been described for a number of areas in the United States such as the Blue Mountains of Oregon and Washington (Thomas 1979), the areas west of the Cascades in Oregon and Washington (Brown 1985a, 1985b), the Sierra Nevada in California (Verner and Boss 1980), Colorado (Hoover and Wills 1984), New England (DeGraaf and Rudis 1986), and the Great Basin (Maser and Thomas 1983). The forest manager should consider, in each case, that the habitat described results from some kind of silvicultural activity.

One needs to weigh the impact of timber management activities on wildlife. There are basically two ways to consider wildlife in forest planning and management. The more traditional way is to develop management plans for one or several species of prime interest. But this does not take into account the habitat needs of all species. Another approach is to consider habitat as the prime determinant of wildlife welfare and to associate wildlife with habitat condition.

Wildlife habitats need to be identified in such a way that they can be considered simultaneously with timber management activities. This is accomplished by equating plant communities and their successional stages with habitats for wildlife. Successional stages are the result of the natural growth and development of plant communities. These stages are sometimes altered by management activities, such as controlling brush, planting or seeding trees or grass, and thinning forest stands. The conditions produced by these activities differ somewhat from natural conditions, but they are roughly equivalent because the structure of the altered forest is similar to natural conditions at various stages of succession. By associating individual wildlife species and groups of species with plant communities and their successional stages, the forest manager can translate standard forest inventories into information on wildlife habitats. The wildlife managers can use forest inventory data to determine the existing species richness and evaluate changes resulting from forest management. Where Forest Plans define the desired future condition of the forest, the wildlife biologist can evaluate the long-term effects on the habitat and its associated wildlife. This will enable the forester and wildlife biologist to work together to produce the best mix of timber, wildlife, and other forest resources to meet society's needs.

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Effects of Timber Management Practices on Range

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Introduction

The world population is projected to increase significantly by the end of this century. To help meet the rising demand for food, production of animal products also will need to increase. This high food demand will increase the pressure on rangelands and require development of ecologically and economically sound land-use concepts. While the need for improved information on rangelands should be stressed, the transfer of known technology for adaptation to local conditions is equally important.

The natural resource ecosystem is a complex community of organisms integrated into their physical and chemical environment. Either through self-delegation, self-preservation, or default, man is responsible for care of the ecosystem. Manipulation of the system is often described as "management." Beneficial management involves manipulation to improve the productivity of one or more natural resources for man while exploitive management results, eventually, in reduction of the system's productivity. **Range** is defined as grassland, shrubland, and forest land producing native vegetation that can be used by grazing animals or lands that have been revegetated naturally or artificially to provide forage that is maintained like native vegetation.

The scope of this chapter is to (1) discuss conflicts and compatibilities among forest range resources, (2) describe tree-forage-livestock relationships, and (3) identify management practices common and unique to the various ecographic forest regions throughout the United States.

Conflicts and Compatibilities

Multiple-use management of forest range to produce timber, livestock, water, and wildlife presents some new challenges when compared with single-use management. Probably the most important are social and economic barriers. For instance, foresters frequently fear that livestock will damage young pine plantations by browsing or trampling, or that cattlemen on southern range will burn young trees in an effort to provide fresh green forage in early spring. Few have seen examples of good integrated management.

Many foresters also believe that stockmen are willing to pay enough for the grazing resource to offset the efforts and expense of adjusting their management plans. Fluctuating livestock economics complicates that issue. Furthermore, many people fear that water quality may be degraded from sediment or pollution due to livestock grazing.

Wildlife and fish biologists sometimes contend that cattle consume excessively large quantities of deer food, especially during winter; in the West they also contend that livestock trample streambanks and destroy large parts of the riparian habitat. Cattlemen counter with the argument that well-managed livestock operations pose no threat to wildlife or timber stands. Conversely, they feel that some benefits accrue from well-managed grazing.

Management must be more intensive to coordinate multiple use on a single piece of land. Some tradeoffs occur in the single-product yield when multiple-use management is applied. However, reductions in goods and services are not always as great as anticipated. At the same time, intensive management may create additional problems. For instance, fertilization could accelerate tree growth and thereby increase the incidence of insects and diseases in trees.

The key to success in multiple-use management is maintaining a balance between the resources. Management guidelines to reduce cattle damage to southern pine regeneration may include: (1) prescribed rotational burning, (2) control of grazing intensity, and (3) location of supplemental feeding or mineral stations. Planted or direct-seeded pines can be regenerated on large open areas under light or moderate grazing intensity. Avoiding high cattle stocking rates during late winter and spring of the establishment year alleviates damage problems. Higher stocking rates later in the establishment and subsequent years have little effect on pine regeneration.

Furthermore, pines appear highly resistant to grazing damage. In an attempt to simulate grazing damage of pines in Georgia, several types of injury were inflicted on slash pine seedlings including removal of needles, removal of the growing shoot, bending the stem parallel to the ground, and stem girdling. These injuries were applied in varying degrees and combinations to seedlings at different ages. The pines recovered quickly from most injuries and mortality was negligible except with complete girdling. Shortleaf and loblolly pines browsed within 2-5 cm (an inch or two) of the ground by rabbits survived and grew as well as unbrowsed trees. If livestock populations are regulated to coincide with forage supplies in the openings, there is little damage to young pines. Deferred or seasonal grazing until trees are 2.4-3.0 m (8-10 ft) tall will reduce damage.

Some tree benefits may accrue because grazing reduces grass competition and removes hazardous fuels in young pine regeneration.

Livestock and wildlife programs can be mutually beneficial. For instance, livestock grazing can benefit wildlife by stimulating new plant growth. Range livestock management usually provides water and supplemental feed or minerals that can be used by some wildlife. Hunting leases can provide an additional source of revenue for the forest landowner.

When livestock and wildlife population requirements exceed food supplies, undesirable competition is created and resources may be damaged. Overuse by livestock for long periods is detrimental to plant species composition and yield, which can cause soil and site conditions to deteriorate. Excessive use by wildlife has similar effects and can damage nearby agricultural crops.

Tree-Forage-Livestock Relationships

Overstory tree density and its canopy cover have a great influence in determining forage yields on forest range. Yields decrease as tree overstory and density increase. Young trees decrease forage yields more than mature trees with similar tree basal areas. Ponderosa pine (*Pinus ponderosa*) stands have relationships similar to the southern pine stands although total forage yields are usually lower in the West than in the South. Canopy cover from the overstory often influences forage nutrients; for example, forage crude protein content is usually higher under shade than in the open while nitrogen-free-extract carbohydrate content is usually higher in the open. However, this is not always true. Cool-season, introduced plants under pines usually do not provide more forage than native plants, but can provide green foliage during winter when native plants are dormant.

Timber supplies apparently are not greatly reduced by concessions to grazing even when trees are planted at wide spacings. Results of past studies show that sawtimber yields at age 30 of unthinned pines planted at 495 trees/ha (200 trees/acre) were greater than from a comparable area planted with 1,480 per ha (600/acre) and then thinned to 990 (400) at age 15; 740 (300) at age 20; and 495 (200) at age 25. Similarly, pulpwood yields at ages 20 to

35 years from plantings of 1,480 trees/ha (600/acre) were more than 90 percent of yields from plantings of 2,470 trees/ha (1,000 trees/acre). Fewer, widely-spaced trees will provide for a shorter rotation. Therefore, planting fewer trees need not necessarily reduce the yield of wood and fiber but it may greatly increase forage yields.

In general, the denser the shade, the less understory vegetation that is produced. Open forests, such as ponderosa pine, and quaking aspen (*Populus tremuloides*), and longleaf pine (*Pinus palustris*), provide voluminous amounts of usable forage, while closed forests of cedar (*Thuja* spp.), hemlock (*Tsuga* spp.), fir (*Abies* spp.) or loblolly pine (*Pinus taeda*) produce little. Natural openings in the forest in the form of meadows, stream banks, and hilltop balds make significant contributions to forage.

Grazing intensity initially does not affect herbage yields on native forest range in the South although botanical composition quickly changes. As a rule, bunch grasses such as bluestems (*Andropogon* spp., *Schizachyrium* spp.) are reduced, while sod-forming grasses such as carpetgrass (*Axonopus affinis*) increase with heavy grazing intensity. Carpetgrass is nearly absent under light or no grazing but increases to be the dominant forage plant after several years of heavy grazing. Prolonged overuse will reduce the sod-forming grass yields. On western forest ranges, grazing intensity significantly affects both yield and composition sooner than in the South. Heavy grazing decreases production and density of palatable plants. Eventually, perennials are replaced by annuals and herbage yields are reduced below optimum.

Rotational burning and grazing in the South improves forage palatability and nutritive content. Cattle concentrate on newly burned range within 1-4 weeks depending on the date of burning and grass growth. Usually, grazing is uniformly heavy throughout the first summer on these fresh burns with little selectivity among the grass species.

Introduced grasses or legumes in the native forest range in the Southeast are established only with land preparation, fertilization, and shrub control. Some improved forages can also be established in longleaf or slash pine (*Pinus elliottii*) forests when litter is removed by burning and fertilizer is applied. Seeding introduced grasses on western forest range has been quite successful, particularly after logging and site preparation. With fertilization, they often provide more forage than native species.

Forest Management Practices and Range

Forest management is important in developing and maintaining a forage resource. Management practices that alter tree overstories influence timber, forage, and wildlife habitat potentials. Forage supplies determine the carrying capacity for livestock and wild herbivores. Understory vegetation provides cover and other habitat needs for wildlife. To efficiently balance timber and forage needs, land managers must implement practices that benefit both.

In general, timber harvest methods that remove groups of trees will open up the forest canopy and provide more forage than single tree selection methods. Coordination of tree harvest, tree regeneration, and livestock grazing on the same land requires intensive range management, especially during early tree reproductive stages, and careful timing of livestock use to coincide with forage availability. Timber harvesting schedules should seek to provide a relatively constant supply of forage that is well distributed over the area under management.

Large blocks of tree harvest (even-aged management) may result in drastic changes in the environment depending on the degree of disturbance from harvest and site preparation. However, these practices can have positive effects on the understory community especially where it has been relatively unproductive prior to harvest because of the dense tree canopy. Following harvests, forbs are first released, followed by grasses and shrubs (if the plant community has a shrub layer). Where prescribed burning is practiced, a flush of legumes may follow the fire. The early successional stages that follow clearcut harvest can produce high forage yields. Then, as the small trees grow older and canopies close, forage production decreases. By scattering harvest units over large areas, the forage resources can be maintained throughout a timber rotation. The number of years that a harvested unit is suitable for grazing depends on the density of the regenerated stand of trees.

Harvesting

At the time of final harvest, more opportunities are generally available for treating the land than at any

other time in the rotation. Action is then appropriate for slash disposal, erosion control, site preparation for tree regeneration, and other cultural treatments. Harvest cuts of any type produce conditions that are more favorable for the growth of forage-producing herbaceous and shrubby plants.

To minimize livestock conflicts during harvest, logging can be done when livestock are off the range. Domestic sheep should be temporarily excluded from areas recently planted to trees.

Silvicultural systems that rely on natural regeneration often minimize potential range conflicts, particularly when the site is already stocked with natural seedlings or when harvested trees and stands are regenerated without benefit of planting or direct seeding as with seed tree, shelterwood, and selection silvicultural systems. Choosing the most effective reforestation method shortens the time the area being reforested is susceptible to livestock damage and also shortens the interval that grazing must be suspended.

Thinning

Commercial or precommercial thinning increases forage. Precommercial thinning of dense pine stands can increase forage yields fourfold. A similar relationship holds for naturally regenerated slash and loblolly pine stands. Commercial thinning is also beneficial because as trees are removed, more light reaches the forest floor. Where pole- and sawlog-size timber stands are regularly thinned and the accumulated litter and logging debris burned using controlled fire, surviving plants and plants colonizing the burned area grow luxuriantly and produce about twice as much forage as under unthinned stands. However, these stands produce half as much forage as treeless range. Intermediate cutting or girdling and poisoning to eliminate competition from undesirable trees, commonly termed timber stand improvement, or TSI, has similar effects on forage as with thinning in upland hardwood and mixed pine-hardwood stands.

Pulpwood forestry, stressing maximum fiber production, has been a common practice in the South. Mechanized harvesting and short pulpwood rotations reduce shading by overstory trees and increase the amount of sunlight reaching the ground and therefore forage production following harvest and regeneration. Similarly, projected increasing demands for southern pine lumber and plywood should shift management toward growing high-quality sawtimber in the South. This may mean wider spacing among trees in order to grow large-diameter trees in a short period of time. More forage can be produced under these conditions.

Other than the relatively short period following regeneration, the next most productive time for understory vegetation in an even-aged pulpwood stand is following precommercial thinning or the first commercial thinning. At this time, the tree canopy has been reduced, allowing grasses, forbs, and shrubs an opportunity to take advantage of increased light from openings in the forest stand. In a sawlog operation, subsequent thinnings increase forage yields only slightly less than those produced under little or no canopy. The least productive period is when tree reproduction totally occupies the site. Competition is most intense between tree and forage species at this time.

Uneven-aged management has a variety of applications including silvicultural systems that employ single tree selection or group selection. Generally, due to the irregular arrangement of openings within a stand being managed by these silvicultural systems, a variety of range vegetation conditions develop. Forage production will vary according to the size and age of individual openings in relation to the height and growth rate of surrounding trees. However, over a large area, single tree and group selection systems usually create relatively stable range conditions over time. Management of the range can easily be coordinated with these systems because changes are slow and widespread, with new openings compensating for openings regenerated with trees over the entire area being managed.

Site Preparation

Techniques for site preparation vary from little soil disturbance to complete tillage. Nothing more than a prescribed burn may be necessary to direct seed or plant cutover longleaf pine stands or old-fields. By contrast, intensive site preparation such as with combinations of chopping, shearing, or windrowing with burning may be needed in loblolly or shortleaf pine (*Pinus echinata*) stands with dense hardwood understories. Sometimes intensive grazing prior to regeneration may substitute in part for site preparation. After site preparation, areas usually produce more forage.

Seeding of introduced or native forage species on sites prepared for forest regeneration may provide more and better forage than native vegetation. When grazing these areas, care must be taken to prevent cattle damage to trees.

When large amounts of debris resulting from harvesting trees (slash) accumulates, it inhibits grasses, forbes, and browse and creates a physical barrier to foraging livestock and wildlife. Therefore, the timely disposal of this slash is important to range management as well as to fuel management. In western forests, prescribed fire, piling and burning, and treatments such as crushing or letting the slash decay are management options for slash disposal. Prescribed burning can have positive effects in slash reduction, nutrient cycling, and vegetation rejuvenation; therefore, scheduling of prescribed burning should be coordinated with grazing schedules. Mechanical piling of slash usually disturbs soil and ground cover, but productive sites recover rapidly. Crushing and chopping treatments tend to incorporate a layer of slash into the first 10-15 cm (4-6 in) of soil. If short-term decay of this slash is imminent, the treatment may have positive effects. If the site is arid and decay is slow, range quality may diminish.

Reforestation

Regeneration of the timber stand in the shortest possible time is generally a major objective and may be a legal requirement following harvest. Intensive management of timber stands implies regeneration of the forest within a relatively few years of harvesting.

Areas disturbed by logging, such as landings, skid trails, and road fills, should be seeded with a mixture of grasses or forbs to control erosion and enhance forage production. These seed mixtures may contain species that are not native to the area but should be palatable both to domestic and wild herbivores. When harvesting timber within areas grazed by domestic livestock, species for seeding should be selected to assist in meeting range management objectives. Mixtures seeded on areas where livestock use is not desirable may include species that are less palatable to livestock, whereas on those where livestock use is desired, seeding mixtures should contain highly palatable and productive species.

Reforested areas can usually be grazed safely if proper management practices are followed. Most damage to tree seedlings occur from trampling when soils are excessively wet and unstable, or from grazing when seedlings are growing rapidly and the new growth is tender and succulent. Livestock mineral deficiencies will also cause browsing where fertilized seedlings are planted. Damage can be prevented if the newly planted areas can be fitted into a grazing plan that avoids these hazardous periods and livestock deficiencies. Seedlings harden off late in the season and the danger of being damaged declines. Also, within a few years young trees grow tall enough so that they no longer are vulnerable to stunting by browsing animals.

Special care must be taken to help meet management objectives on areas open to grazing and efforts should be accelerated to distribute livestock use evenly over the suitable range. Animal concentration is the most common source of seedling damage. Water and salt can be strategically placed to help obtain animal distribution and avoid concentration. In some cases, these must be limited to locations outside, or near the edge of regeneration units.

If necessary, repellants or cages may be used to protect seedlings from grazing damage, especially by wild herbivores. Commercially available repellants reduce the attractiveness to grazing animals of coniferous seedlings in contrast to other plants. Cages constructed of plastic mesh (tubes) are also used effectively in protecting seedlings. Although these are expensive and the seedlings are still subject to trampling damage, tubes are quite widely used in commercial forest operations, especially in the West.

Uncontrolled livestock may concentrate and graze or trample tree seedlings; however, damage can be reduced or eliminated through management techniques such as rotational prescribed burning, fencing, livestock supplementation, water placement, and stocking with the right number and class of animals. Most damage can be eliminated by balanacing animal populations with forage supplies or through deferred grazing until pines are 2.4-3.0 m (8-10 ft) tall. Fences to eliminate livestock grazing use entirely may be required around some newly established plantations. On the other hand, some benefits may accrue to tree seedlings if grazing reduces herbaceous competition and fuels prior to and while pines are small and vulnerable.

Reforestation practices influence forage yields through manipulation of the number of trees on a given area. Because tree crowns occupy all available

space more slowly at wide than narrow spacing, spacings of 3.0 by 3.7 or 3.7 by 3.7 m (10 by 12 or 12 by 12 ft) are more favorable for forage production than spacings of 1.8 by 1.8 or 1.8 by 2.4 m (6 by 6 or 6 by 8 ft). Dense, direct-seeded or naturally-regenerated stands usually reduce forage production sooner than planted stands. In closely spaced tree stands forage supplies are greatly diminished after age 5 years whereas wider spacings provide adequate forage for 10 years or more. One approach to maintaining an open canopy longer into a rotation is to plant trees 1.2-1.8 m (4-6 ft) apart within rows and 4.6-6.1 m (15-20 ft) apart between rows. These tree planting configurations maintain good forage production for 12-15 years before tree crowns meet, reduce light reaching the ground, and diminish forage yields. Another approach is to plant trees fairly close in double rows, with wide spaces between the double rows. For example, planting two rows of slash pine 1.2 m (4 ft) apart in rows and 2.8 m (8 ft) apart between rows with 12.2 m (40 ft) between sets of double rows, that is, a 1.2 by 2.8, 12.2 m (4 by 8, 40 ft) spacing or a 1.8 by 2.4, 7.3 m (6 by 8, 24 ft) spacing promises that an open canopy and a grazeable forage resource can be maintained throughout the timber rotation. Cluster plantings provide another opportunity to benefit both trees and forage where clusters of five trees are spaced about 7.6 m (25 ft) apart. Dominant trees within each cluster are selected for sawlog retention while subdominants are removed through early commercial harvest.

Fertilization

On southern pine forest-range sites, fertilization has produced tree volume gains of more than 40 percent. In some instances, both forage and pine growth increase with fertilization; however, fertilization probably is not economical when applied to native forages to improve nutritive value or yields.

Prior to fertilization soils should be analyzed to determine nutrients available for plant growth. Once this information is obtained, the correct fertilizer mix can be prescribed. The time of fertilizer application varies by region, but in general it should be in the spring or late fall.

Prescribed Burning

Use of intentionally set, controlled fire (prescribed burning), a common timber management practice in the South, reduces the hazard from wildfire, controls brown-spot needle blight (*Scirrhia acicola*) disease in longleaf pine seedlings, reduces competition from undesirable plants, increases visibility for tree marking and logging, and reduces debris from timber harvesting. Prescribed burning also kills the tops of brush and understory hardwoods, reduces litter accumulation, and provides palatable and nutritious green forage early in spring, which attracts grazing animals. While burning reduces shrubs, it generally enhances resprouting and seldom kills if burning is done when the plants are dormant. Burning in winter on a 3- to 4-year cycle generally meets range management objectives by stimulating nutritious new spring growth and increasing herbage yields by removing accumulated litter. Burning in the spring stimulates height growth of longleaf pine. Burning during summer usually proves harmful for it may kill small pines and possibly destroy nests of quail and other wildlife. The judicious use of controlled fire may enhance esthetic values by maintaining open, parklike stands and increasing the visibility of flowering plants.

Direct effects of fire on wildlife vary widely. Although some mortality has been reported, few animals are directly killed by controlled fire.

Grazing Systems

Grazing systems place primary emphasis on improving or maintaining species composition of range vegetation with minor emphasis on grazing animal needs. Multipasture, rotational grazing systems generally improve availability of forage and give herbaceous and woody plants a chance to regain vigor by controlling animal distribution and providing rest from animal grazing. Single-pasture, continuous grazing systems usually lack good animal distribution and plants are not given deferment or rest from animal use. A rotational burning system, which has been a highly successful grazing system in the South, markedly increases utilization of herbage and distribution of livestock. When range is burned on a 3-year rotation, livestock grazing use is concentrated on the most recent burn and is less on the second- and third-year burn, so that plants have a chance to regain vigor and produce seed. Burning improves forage availability by removing accumulated old plant material and stimulating succulent new growth that is relatively high in crude protein.

Silvicultural Systems and Range

Any management practice that alters the overstory of trees will change the amount and composition of forage. Timber management practices discussed in the earlier section--site preparation, reforestation, thinning or harvesting, and prescribed burning--all affect the forage resource. Regardless of the cultural practices or silvicultural system used in forest management--selection, shelterwood, seed tree, or clearcutting--the effect on forage resources is proportional to the amount of tree cover removed and to site damage attributable to logging practices. Effects may be long lasting. When shading is reduced, forage resources increase. Severity of soil disturbance affects rate of recovery of the understory forage. For example, clearcutting followed by mechanical site preparation, which results in a large amount of soil disturbance, requires a longer forage recovery period than a selective or seed tree harvest with little accompanying understory and soil disturbance. On greatly disturbed sites, forage species may be introduced by reseeding to avoid the delay in forage recovery or to alter the forage species.

Ecographic Forest Regions and Range

Eastern Hardwoods

Upland hardwood forest types containing less than 25 percent pine occupy nearly 60.7 million hectares (150 million acres) in the Eastern United States. Palatable forage production is so low within these types that livestock grazing is seldom important. The terrain varies from plateaulike to hilly or mountainous. Oaks (*Quercus* spp.) are the primary tree species. Several species of hickory (*Carya* spp.) are common while blackgum (*Nyssa sylvatica*), sassafras (*Sassafras albidum*), eastern red cedar (*Juniperus virginiana*), and persimmon (*Diospyros virginiana*) also occur frequently. Stands of oak and hickory account for more than 75 percent of eastern upland hardwoods while oak-pine stands make up the remainder. Redbud (*Cercis canadensis*), blackhaw (*Viburnum prunifolium*), and blueberries (*Vaccinium* spp.) are common shrubs. Bluestems, Indiangrass (*Sorghastrum nutans*, switchgrass (*Panicum virgatum*), and legumes comprise the most important forage plants. Composites are the most abundant forbs. Thousands of hectares (acres) of low-value hardwoods have been converted to grass pastures, increasing forage production by as much as 4.5 tonnes/ha (2 tons/acre). Some upland hardwood-bluestem ranges have been improved by seeding fescue (*Festuca* spp.) grasses. Nutritional deficiencies in range forage, especially during winter, are alleviated with supplements. White-tailed deer (*Odocoileus virginianus*), turkeys (*Meleagris gallopavo*), bobwhite quail (*Colinus virginianus*), rabbits (*Sylvilagus* spp.), and squirrels (*Sciurus* spp.) are found in this type.

The sugar maple-beech-yellow birch type and aspen-birch forests are mainly in the New England, middle Atlantic, and Lake States. They are not usually grazed by livestock.

Bottomland hardwoods occupy nearly 40.5 million hectares (100 million acres) in the East. Oak-gum-cypress forests are mainly in the southern Delta. These, too, are not usually grazed by livestock.

Northeastern Conifers

The northeastern conifers consist of about 12.1 million hectares (30 million acres) of spruce-fir and white pine, red pine, and jack pine forests in the Lake States and Northeast. Common associates include oaks, eastern hemlock (*Tsuga canadensis*), aspen, birch (*Betula* spp.), northern white cedar (*Thuja occidentalis*), maple (*Acer* spp.), and tamarack (*Larix laricina*). Forage production is low. These forests are seldom grazed.

Southern Conifers

Four principal forest types are found in the South: (1) longleaf pine-slash pine, (2) loblolly pine-shortleaf pine, (3) loblolly pine-hardwood, and (4) Shortleaf Pine-Oak. These types are found on public and private lands; the proportion of land that is forested varies from none to about 100 percent. The longleaf pine-slash pine type occupies about 12.2 million hectares (30 million acres) along the lower Coastal Plain from South Carolina to east Texas. The area produces more forage per unit area than any other forest type in the South. Major forages are bluestems in the west gulf coast and wiregrass (*Aristida stricta*) in Georgia and Florida. Other forages include panicums (*Panicums* spp., *Dichanthelium* spp.), paspalums (*Paspalum* spp.), dropseeds (*Sporobolus* spp.), native forbs, and occasional shrubs. Composites such as swamp sunflower (*Helianthus angustifolius*), eupatoriums (*Eupatorium* spp.), grassleaf goldaster (*Heterotheca graminifolia*), blackeyed susan

(*Rudbeckia hirta*), and goldenrods (*Solidago* spp.) are the largest group of forbs. Legumes are often abundant but generally have limited forage value. Seeds of many forbs are valuable as food for birds and small animals. Common shrubs include southern waxmyrtle (*Myrica cerifera*), shinning sumac (*Rhus copallina*), blueberries, gallberry (*Ilex glabra*), and saw-palmetto (*Serenoa repens*). Oaks, tupelo (*Nyssa* spp.), and sweetgum (*Liquidambar styraciflua*) are common along with the predominant longleaf and slash pines. Periodic burning is common in the longleaf pine-slash pine type, and forage yields commonly exceed 2.24 tonnes/ha (a ton/acre) on cut-over forest land or under sparse tree canopies. Forage digestibility and nutritive values are highest in spring when forage plants are growing rapidly and lowest during winter when most of the plants are dormant. Digestible energy and crude protein of forage are below those required by cattle during late fall and winter; phosphorus is deficient year long, while calcium and vitamin A are generally adequate. White-tailed deer is the principal big game animal while bobwhite quail is the predominant game bird. Turkeys, doves (*Zenaidura macroura*), squirrels, and rabbits are also important game species within the longleaf pine-slash pine type along with many songbirds, mammals, amphibians, and reptiles. The longleaf pine-slash pine type is esthetically pleasing and also provides other recreational opportunities.

About 22.3 million hectares (55 million acres) of the loblolly pine-shortleaf pine, loblolly pine-hardwood, and shortleaf pine-oak forest types are found on the upper Coastal Plain. These types occur in a belt 240-480 km (150-300 mi) wide from eastern Texas to northeastern Virginia. Primary plants for livestock are bluestems under open pine stands or in clearcuts, and spikegrass (*Chasmanthium* spp.) where trees are dense. Switchgrass, purpletop (*Tridens flavus*), Indiangrass, and other grasses found in the longleaf pine-slash pine type are also scattered throughout the loblolly pine-shortleaf pine type. Shrubs and hardwood trees are abundant because fire generally has been restricted. Common woody understory includes American beautyberry (*Callicarpa americana*), yaupon (*Ilex vomitoria*), greenbriers (*Smilax* spp.), hawthorns (*Crataegus* spp.), and blueberries. Common hardwood trees include oaks, gums, hickories, dogwood (*Cornus florida*), maples, and American beech (*Fagus grandifolia*). This forest type, which tends to have denser timber stocking than the longleaf pine-slash pine type, usually produces less herbage even though it potentially can produce more than 4.5 tonnes/ha (2 tons/acre). Nutritive values of forage are similar to those of the longleaf pine-slash pine type; however, ranges in loblolly pine-shortleaf pine, loblolly pine-hardwood, and shortleaf pine-oak types provide the most extensive native habitat for white-tailed deer and constitute some of the best habitat for wild turkey. Squirrels are common where mast-producing hardwoods and den trees are present. Deer and cattle have overlapping diet preferences during winter in forests where grass yields are limited.

Pacific Coast Conifers

Douglas-fir-western hemlock forests occupy more than 12.1 million hectares (30 million acres) mainly on the Pacific coast west of the Cascade Range. These forests also occur in California and the Rocky Mountains. Common woody plants (trees and shrubs) in the stands are maple, rock-spirea (*Holodiseus* spp.), filbert (*Corybus americana*), blueberry, snowberry (*Symphoricarpus* spp.), barberry (*Berberis* spp.), current (*Ribes* spp.), blackberry (*Rhus* spp.), ninebark (*Physocarpus* spp.), rose (*Rosa* spp.), and spirea (*Spirea* spp.). Palatable herbage yields, primarily pinegrass (*Calamagrostis rubescens*) and sedge (*Carex* spp.), under trees are usually too low to support livestock grazing. However, areas regenerated using the clearcut and shelterwood silvicultural systems can support grazing, particularly sheep, when slopes are not too steep.

Western Inland Conifers

Ponderosa pine forests occupy large areas in eastern Oregon, Washington, California, and throughout the Rocky Mountains. The total area approximates 12.1 million hectares (30 million acres). A contiguous stand of about 480 km (300 mi) of ponderosa pine extends from central Arizona to southwest New Mexico. Ponderosa pine forests are characterized as open, parklike stands with excellent ground cover of grasses (pinegrass, fescue, and muhly (*Muhlenbergia montana*)), sedges, and forbs, or with an understory of low- to medium-height shrubs. The shrubs may vary from antelope bitterbrush (*Purshia tridentata*) to bearmat (*Chamaebatia* spp.).

Because forage production is high, open stands of ponderosa pine support a large livestock industry. In the northern Rocky Mountains and the Pacific Northwest, ponderosa pine is maintained by periodic, naturally occurring fires in the understory. With fire

suppression, Douglas-fir (*Pseudotsuga menziesii*) and the true firs (*Abies* spp.) are reproducing and, thereby, changing the species composition and overall complexion of this forest. These changes in species composition also cause a reduction in forage as tree stocking becomes more dense. Forage yields can be maintained by timber mangement, periodic thinning and stand regeneration, or prescribed burning. Both forage quantity and quality can be increased if selected grasses are seeded during logging. Other forest types of this region are dominated by white fir (*A. concolor*), grand fir (*A. grandis*), Engelmann spruce (*Picea engelmannii*), and subalpine fir (*Abies lasiocarpa*), intermingled with larch (*Larix* spp.) and other spruces (*Picea* spp.). These types seldom produce sufficient forage to support livestock except on harvested and open forest areas.

Summary and Conclusions

The potential for simultaneous production of timber, livestock, and wildlife provides excellent opportunities for resource development in the United States. Natural diversity in forests without management may limit rather than enhance resource productivity. However, diversity through management provides habitat for wildlife, forage for livestock, and high yields of timber. Judicious planning is necessary to realize optimum benefits of any or all resources. Planning becomes difficult when several disciplines are involved. Multiple-product yields generally require adjustments in management and some tradeoff in single-product yields.

Forage yields vary depending on soil and climate along with the influence of tree density, age, and type. Interrelationships among livestock, timber, and wildlife are generally complex; therefore, multiple-use management requires coordination, understanding, and planning. Some general concepts are known that when used in management minimize conflicts among uses. Livestock must be properly managed or excluded from pine plantations. Livestock browsing can benefit wildlife by stimulating new plant growth. Land managers must understand tree-forage relationships to achieve proper and efficient multiple use on the forest range.

Successful tree regeneration with cattle grazing requires deferment of grazing, lighter initial stocking rates of livestock, or a grazing system to overcome livestock concentrations and mineral deficiencies. It helps to arrange for distribution of livestock with burning, feeding, fencing, or other means. Early thinnings in young tree stands not only enhance sawtimber production but also open the canopy of trees, permitting more light to reach the understory, and thereby increasing forage production for livestock and wildlife. Livestock and wildlife can be mutually benefited under coordinated planning and management. Economic returns are usually greater from multiple products of food, fiber, and wildlife than from a single output. Equally important, flexibility in land management aids in surviving poor markets. Forest ranges of the United States have great potential and offer many opportunities. Researchers must continue to define tradeoffs and resolve conflicts. At the same time, resource managers must work cooperatively to realize the optimum benefits of natural and planned diversity in the forest range.

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Effects of Timber Management Practices on Recreation and Esthetics (Visual Resource)

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Introduction (A Historical Perspective)

The need to provide high-quality settings for recreation and viewing has again been established through The Report of the President's Commission (1987). Included were the findings of a national survey that asked for which attributes adults consider in choosing outdoor recreation areas. The number one attribute was "natural beauty."

The following brief historical perspective allows readers to gain a greater understanding of the evolution of recreation and concern for the visual resource on national forest land. Subsequent sections will report on the current techniques and practices used to integrate recreation and visual resources with silvicultural practices.

The use of forested landscapes to provide quality recreation and scenic settings has changed throughout history. As might be expected, early settlers viewed forest lands almost exclusively for utilitarian purposes. Forests were cleared for agriculture or were exploited as a source of lumber, firewood, or game. The amenity values of scenery or the opportunities for recreation were of little importance.

However, the attitudes of Americans toward their forests were assuming new forms and changing patterns between 1850 and the early 1900's (Cox and others 1985). Cox and others contend that the European romantic movement influenced an appreciation of "natural" landscapes. This did not mean, however, the unconquered wilderness of America--it generally included only the more pastoral scenes of landscapes that had been settled for centuries. This "natural" landscape concept is of importance to this Nation in that the world's first major public park--Central Park in New York City, designed in 1858 by landscape architect Frederick L. Olmsted--exhibited the "natural" concept. Olmsted wanted an "idealized" rural landscape that emphasized pastoral settings. Cox and others contend that our pastoral urban parks movement and the selection of national parks based primarily on geologic and scenic value structured our "esthetic" for landscape appreciation. In most national parks, stands of trees were generally incidental in determining the overall value for recreation or landscape beauty.

Early management of those Federal lands that later would become part of the National Forest System was directed primarily at timber and water management. Utilitarian resource needs that could be sustained were used to structure early forest policy. Forest recreation was allowed to the extent it did not interfere with utilitarian practices. Concern for the visual landscape was not an issue.

Historian William Tweed (1980) researched the recreation program of the Forest Service from 1891 to 1942. He reports that forested lands had been used for pleasure long before the "Forest Reserves Act" of 1891 and that Americans' attitudes toward outdoor recreation and scenic resources were undergoing significant change by the end of the 19th century. Tweed noted that Forest Service annual

reports first mentioned recreation activities in 1912, the Term Occupancy Act of 1915 allowed private use of recreation structures on public lands, and that in 1916 the Forest Service constructed what was reported to be their first "modern" campground. Tweed also reported on the early years of a recreation program, including the work of Frank Waugh and Arthur Carhart. In 1917, landscape architect Frank Waugh was hired as a consultant to prepare a national study of recreational uses of the national forests. Waugh's report included strong arguments for the development of a formal recreation program and recommended that certain Forest Service lands should be developed as "scenic reservations" that would exclude uses that might detract from recreation experiences. Waugh's study, along with a move to accommodate recreation and scenic preservation in the National Forest System, led to the hiring of the first recreation site planner in 1919. Arthur Carhart studied forest recreation problems and opportunities. As a trained landscape architect, he was able to provide detailed recreation site plans and large-scale recreation planning studies involving several States and millions of acres of national forest land. In addition to his professionally planned recreation facilities, Carhart is credited with large-scale recreation plans that included--for the first time--the establishment of areas for wilderness, or very limited recreation development, in areas with outstanding natural settings.

Tweed reports that after the early 1920's there was very little overall supervision of the recreation program. Recreation facilities were modest, small, and did not interfere with other forestry activities. The New Deal years of the 1930's changed the recreation development philosophy. With the availability of Civilian Conservation Corps manpower and funding, along with strong competition from other Federal and State recreational facilities, the Forest Service developed a new policy of planning and designing high-quality recreational facilities. This included the development of shelters, bathhouses, and amphitheaters using the rustic style of architecture. Major recreational improvements followed an approved master plan. Tweed reports that World War II brought other national priorities that superseded the recreation program.

In the late 1950's, a new program, titled "Project Out-of-Doors," again placed the Forest Service in the role of a major provider of quality recreation facilities. This extensive recreation development program brought many visitors into new areas of the forest. A second major development of the late 1950's that affected recreation and scenery was the increase in timber harvest--from 8.55 million m^3 (1.5 billion fbm) in 1941 to 47.31 million m^3 (8.3 billion fbm) in 1961. This created a situation in which recreation users and casual forest visitors were not always confined to campgrounds and roadside views. They used new roads and experienced a changing landscape character--from natural to sometimes highly modified.

The 1960's were important years for the development of visual resource and recreation planning. The Multiple Use-Sustained Yield Act of 1960 provided increased agency recognition of recreation. Greater recreation facility development caused the designation of narrow strips of land along some roads and trails to be zoned as Travel Influenced Zones (TIZ) and selected lakes and streams to be zoned as Water Influenced Zones (WIZ). These areas were intended to afford visual protection to sensitive areas. The Wilderness Act of 1964 also provided unique recreation opportunities and preserved natural beauty.

In addition, the early 1960's were a time of change in timber harvest practices. The concept of selective harvesting was replaced by clearcutting in many areas of the Forest Service. The practice of even-aged management "clearcutting" would later create high levels of concern from some publics. The esthetic "problems" of even-aged management were also experienced in Britain (Crowe 1966) and visual mitigation techniques were developed for their extensive pine plantations. Many of these techniques were later used by the landscape architects and others to mitigate adverse visual impacts of clearcuts in the USDA Forest Service. Burton Litton (1968) provided a process for conducting visual inventories in the general forest zone (areas outside wilderness, TIZ, and WIZ). This process was important in structuring the Visual Management System (VMS) developed in 1974.

The appearance of the forest was further recognized by two significant events. The 1965 Natural Beauty Conference, initiated by President Johnson, recognized that management of the natural beauty of the land must have a course of action to protect and enhance the beauty. Later, the National Environmental Policy Act of 1969 required esthetically and culturally pleasing surroundings, methods, and procedures to quantify environmental amenities, and a systematic interdisciplinary approach to ensure that the environ-

mental design arts were integrated in planning and decision-making.

In response to these events and other public concerns, the Forest Service established a program to develop a series of landscape management handbooks. The first, "National Forest Landscape Management" (USDA Forest Service 1973) provided a servicewide approach to landscape management terms and concepts. Handbooks developed since 1973 include: "The Visual Management System" (USDA Forest Service 1974), "Utilities" (USDA Forest Service 1975), "Range" (USDA Forest Service 1977a), "Roads" (USDA Forest Service 1977b), "Timber" (USDA Forest Service 1980), "Ski Areas" (USDA Forest Service 1984), "Fire" (USDA Forest Service 1985), and "Recreation" (USDA Forest Service 1987).

The "Visual Management System" was the single most important handbook (Schweitzer 1984). Through extensive land planning, the VMS process has been applied to all of the approximately 76.9 million hectares (190 million acres) of land managed by the Forest Service. It provides standards and guidelines that, when applied through the planning process, can be used as direction in determining the acceptable level of visual alteration of the landscape.

In 1976, a research report provided a methodology for the scientific measurement of the public's perception of scenic beauty (Daniel and Boster 1976). This process, which is known as the "Scenic Beauty Estimation Method," has been used extensively by researchers to determine the different levels of scenic beauty for near-view landscape perception.

In the late 1970's, land management planning in such agencies as the USDA Forest Service became a mandate through the passage of the National Forest Management Act, 1976, and the Renewable Resources Planning Act, 1974. It became clear that a good framework to integrate recreation into multiple-use land management planning did not exist.

Any such framework needs to address the relationship between recreation settings, activities, and experiences. It also needs to provide a method of determining supply and demand with similar variables. Lastly, it must provide a way of assessing the effects of other resource activities on recreation opportunities and visa versa. Central to all these issues was the necessary goal of ensuring a diversity of recreation opportunities. The need for such a spectrum of opportunities had been in the recreation literature for years. In the late 19th and early 20th centuries, Fredrick Law Olmstead called for providing a variety of outdoor options. Carhart (1920) was among the first Americans to propose managing National Forests to provide different types of recreation experiences. J.V.K. Wagar (1951) was explicit in his call for "complete recreation land systems" that range "from the flower pot in the window to the wilderness."

The concept of a spectrum of opportunities is reflected in most of the systems developed over the past two decades. The Bureau of Outdoor Recreation system was one of the first and was widely used in the 1960's. Later, the Recreation Inventory Instructions (RII) advanced the spectrum idea by using five different recreation experience levels. In 1974, the Recreation Opportunity Inventory and Evaluation (USDA Forest Service 1974) was developed, building on the logic of RII. It classified land areas in terms of their ability to provide specific types of recreation experiences.

Most of these systems, however, viewed recreation opportunity primarily as an opportunity to participate in a recreation activity. It wasn't until the late 1970's and early 1980's that Driver, Brown, Clark, Stankey, and McConnell, in concert, developed the Recreation Opportunity Spectrum (ROS) system. Recreation was portrayed as a combination of activity, setting, and experience opportunities.

Planning Systems

Recreation Opportunity Spectrum System

The Recreation Opportunity Spectrum (ROS) helps provide a framework for thinking systematically about the provision and management of outdoor recreation opportunities. It builds on the phenomenon that people seek different kinds of settings in which to recreate in various desired activities, and they look for different kinds of psychological outcomes or experiences from these engagements. Some desire solitude, tranquility, and closeness to pristine nature, while others look for opportunities to meet and observe new people and view attractive scenery. Some seek risk, challenge and self-reliance, while others look for comfort, convenience, and relaxation. What people seek changes, both over time and as they recreate in different social situations. Desired recreation

experiences change as people move from adolescence to adulthood. They also change if one is recreating with the family, close friends, or perhaps even by oneself.

The principle responsibility of management is to provide a broad spectrum of opportunities and to help visitors find their desired set of experiences. The key to this is providing a diverse range of settings and activity opportunities. For management purposes, the settings along the spectrum have been given names. Their general setting characterizations are outlined below.

ROS Setting Characterization					
Primitive	**Semi-primitive Nonmotorized**	**Semi-primitive Motorized**	**Roaded Natural**	**Rural**	**Urban**
Area is characterized by essentially unmodified natural environment of fairly large size. Interaction between users is very low and evidence of other users is minimal. The area is managed to be essentially free from evidence of human-induced restrictions and controls. Motorized use within the area is not permitted.	Area is characterized by a predominantly natural or natural-appearing environment of moderate-to-large size. Interaction between users is low, but there is often evidence of other users. The area is managed in such a way that minimum on-site controls and restrictions may be present, but are subtle. Motorized use is not permitted.	Area is characterized by a predominantly natural or natural-appearing environment of moderate-to-large size. Concentration of users is low, but there is often evidence of other users. The area is managed in such a way that minimum on-site controls and restrictions may be present, but are subtle. Motorized use is permitted.	Area is characterized by predominantly natural-appearing environments with moderate evidences of the sights and sounds of man. Such evidences usually harmonize with the natural environment. Interaction between users may be low to moderate, but with evidence of other users prevalent. Resource modification and utilization practices are evident, but harmonize with the natural environment. Conventional motorized use is provided for in construction standards and design of facilities.	Area is characterized by substantially modified natural environment. Resource modification and utilization practices are to enhance specific recreation activities and to maintain vegetative cover and soil. Sights and sounds of humans are readily evident, and the interaction between users if often moderate to high. A considerable number of facilities are designed for use by a large number of people. Facilities are often provided for special activities. Moderate densities are provided far away from developed sites. Facilities for intensified motorized use and parking are available.	Area is characterized by a substantially urbanized environment, although the background may have natural-appearing elements. Renewable resource modification and utilization practices are to enhance specific recreation activities. Vegetative cover is often exotic and manicured. Sights and sounds of humans, on-site, are predominant. Large numbers of users can be expected, both on-site and in nearby areas. Facilities for highly intensified motor use and parking are available, with forms of mass transit often available to carry people throughout the site.

Figure 1--*The spectrum of recreational opportunites in areas ranging from an unmodified natural environment to an urbanized environment.*

As illustrated in figure 1, the setting is defined as the combination of physical, biological, social, and managerial conditions that give a place recreational value. The setting is the central focus of the ROS. Three important reasons underlie this focus. First are the setting attributes that tend to facilitate or discourage certain experiences. For example, unmodified natural settings of large size, with few other people, and difficult to access, tend to foster feelings of solitude, self-reliance, and closeness to pristine nature; whereas settings with easy access, facilities for large numbers of people, and managed landscapes offer opportunities for meeting and observing others, feeling secure and comfortable, and viewing natural appearing scenery. Second is the setting that management can influence. Although the end product of recreation management is the experience that visitors realize, experiences cannot be directly controlled by management. Experiences are the product of people's psychological processes, shaped by their individual backgrounds, previous experiences, knowledge, and other factors that lie beyond direct control by management. Managers can only offer the opportunity for experiences to happen. Settings, on the other hand, are subject to managerial control or influence and thus warrant particular attention. Third, a focus on settings helps provide a basis for understanding the relationship between recreation and other forest uses. Because the setting is a common unit of analysis, whether we are talking about timber management, wildlife habits, or recreation, we can better see how other actions, such as timber harvesting or roadbuilding, will affect the nature of a recreation opportunity and, conversely,

how the decision to manage for a particular recreation opportunity will affect other activities in the area.

Recreation Opportunities

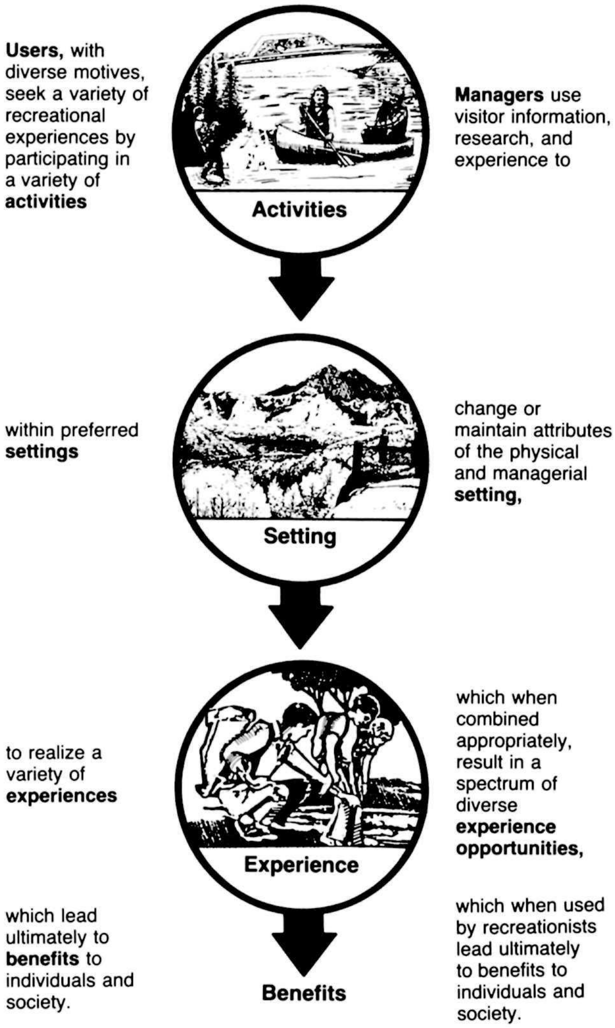


Figure 2--*The preceding sketch helps to summarize the relationships just discussed.*

There are seven setting indicators that tend to facilitate certain experiences. They include (1) access, (2) remoteness, (3) visual quality (resulting from nonrecreation uses), (4) facilities and site modifications, (5) visitor management, (6) social encounters, and (7) visitor impacts. (See chapter 60 of the "ROS Users Guide" for more detail.) The relationship between silviculture and those indicators that might be affected in achieving recreational objectives through silviculture are discussed in the section entitled "Vegetative Management in Recreation Settings."

Visual Management System (VMS)

The purposeful management of the landscape's appearance is mandated on Federal land by law and through the interests of a concerned public. The approach used by the Forest Service is titled "The Visual Management System" (USDA 1974). This descriptive approach guides the inventory and analysis of what is termed the landscape's visual resource.

The descriptive approach is an orderly process that identifies landscape features considered to be relevant to the overall quality of the visual source. The studies are conducted by environmental designers--usually landscape architects--to determine the relative attractiveness and management sensitivity of various areas of the national forest. Decisionmakers use the inventory and analyses to develop land management objectives. Concerned publics are encouraged to comment on managing the visual resource during the public involvement process.

"The Visual Management System" includes an explanation of major premises, important terms, and the "system" that determines the landscape's variety class, sensitivity level, and recommended visual quality objective.

Premises--Very little scientific knowledge about managing forested landscapes for visual purposes was available at the time VMS was developed, hence the use of premises or assumptions to provide overall direction. Some of the more significant premises include: forest visitors have an image of what they expect to see in national forests, all lands are viewed, view duration is critical, viewing distance is critical, diverse landscape character is important, and the visual impact of management activities is critical.

Some important terms used in the inventory and analysis process include:

Landscape character type--Large physiographic areas of land that have common characteristics of landforms, rock forms, water forms, and vegetative patterns.

Distance zones--The distance between the observer and the landscape viewed. Three zones are usually established:

1. Foreground--0.4-0.8 km (0-1/4-1/2 mi).
2. Middleground--0.4-0.8 up to 4.8-8.0 km (1/4-1/2 up to 3-5 mi).
3. Background--4.8-8.0 km (3-5 mi) to infinity).

Dominance elements and management activities--Both the natural landscape and management activities are explained in design terms of form, line, color, and texture.

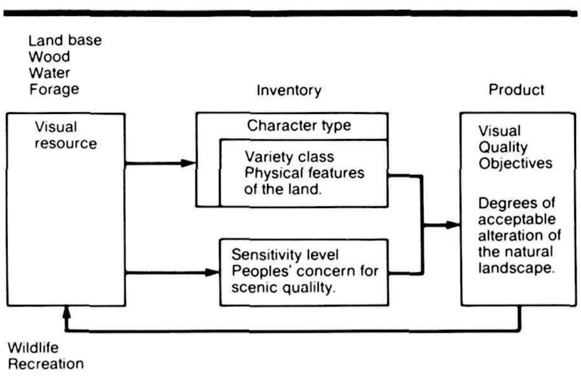


Figure 3--*The visual management system applies to all management activities on all national forest lands.*

Variety Class Determination--The landscape is classified into three variety classes that identify the scenic quality of the natural landscape:

Class A--Distinctive Scenic Quality.
Class B--Common Scenic Quality.
Class C--Minimal Scenic Quality.

The differences are based on the premise that all landscapes have some scenic value, but that those with the most variety or diversity have the greatest potential for high value. The rating is derived from landscape features such as landforms (steepness of topography), water forms (lakes, rivers, streams), rock formations, and vegetative patterns (trees, shrubs, grasses). But the comparisons are only made within the same physiographic character type--therefore mountain landscapes are not compared with flat landscapes, or western landscapes with eastern landscapes. The variety classes are mapped as shown in Agriculture Handbook 462 (USDA Forest Service 1974).

Sensitivity Level Estimation--Sensitivity levels are an estimate of peoples' concern for the scenic quality of national forests.

Lands viewed from travel routes (roads and trails), use areas (campgrounds, visitor centers, communities), and water bodies (lakes, streams, reservoirs) are identified and rated for the public's concern for esthetics. The sensitivity levels are mapped using distance zone information of foreground, middleground, and background. See Agriculture Handbook 462 (USDA Forest Service 1974).

Level 1 - Highest Sensitivity.
Level 2 - Average Sensitivity.
Level 3 - Lowest Sensitivity.

Visual Quality Objectives (VQO)--The visual quality objectives are designed to establish standards for the visual management of the landscape.

Based upon the importance of esthetics, each VQO describes a different degree of acceptable alteration of the natural landscape.

(P) Preservation--only ecological change.

(R) Retention--management activities that are not visually evident.

(PR) Partial Retention--management activities that remain visually subordinate to the characteristic landscape.

(M) Modification--management activities may dominate, but mitigation techniques are used to provide a natural occurrence when viewed in foreground or middleground.

(MM) Maximum Modification--management activities may dominate, but should appear as a natural occurrence when viewed as background.

Mapping Visual Quality Objectives--At this point in the process, all lands have been mapped for scenic quality (variety class maps) and the public's concern for scenic quality (sensitivity level maps). These maps are combined with the visual quality objectives to produce a map that combines all of the inventory and analysis information. See Agriculture Handbook 462 (USDA Forest Service 1974) for examples.

The process as explained, or a close approximation thereof, has been used to develop a visual inventory of the entire 76.9 million hectares (190 million acres) of national forest land. These maps are used to develop long-term integrated resource plans for the

forest. To fully understand the process used, readers should review Agriculture Handbook 462 (USDA Forest Service 1974).

Research Support--Landscape architects in the Forest Service are strongly supportive of the VMS approach and agree that it has changed the way the visual resource is managed on the ground (Laughlin and Garcia 1986). Their study also revealed that sensitivity level establishment needs more research and refinement.

A question that is frequently asked is whether visual quality is attained in timber harvesting. "In planning the visual objectives for a project, the landscape architect, in effect, acts on behalf of the viewing public" (Benson and others 1985). This study of 25 northern Rocky Mountain timber harvest areas concluded that while there were some differences between the VQO planned and what was attained, the overall concensus was that most areas met the planned VQO. The authors also concluded that the results of their research "...support the idea of a system of visual quality objectives based on the degree of acceptable landscape modification" and that "...visual management criteria and guidelines can reduce the visual impact of harvesting, particularly in the more restrictive VQO categories."

Technical and Conceptual Support

VIEWIT

This is a computerized technique for delineating lands that are viewed from single or multiple observation points. The process was developed in 1968 by the Forest Service (Amidon and Elsner 1968). The results of the process allow the development of large overlay maps that can be used to assist in visual management decisions related to timber harvesting, mining, ski runs, fuelbreaks, and road development. It can also be used in land planning to establish "seen" area zones, as part of the Visual Management System. Another use is the process of Visual Absorption Capability (VAC) mapping, which determines the landscape's ability to visually absorb development impacts.

VIEWIT maps contain grid cells that provide either numeric or gray shade values of information for a particular landscape area. The VIEWIT process (Travis and others 1974) provides many basic analytical capabilities that include visible terrain , land elevation, slope, slope direction relative to the observer, and the distance between the observer and visible terrain.

An early use of VIEWIT (Johnson 1974) illustrated the landscape assessment of alternative management strategies. Of the 19 selected viewpoints from a proposed road location, it was determined that almost 4,050 hectares (10,000 acres) of landscape could be viewed from at least one observation point, with about 688 hectares (1,700 acres) viewed from 5 points, and only 2.4 hectares (6 acres) viewed from 10 observation points. This type of information provided resource managers with landscape data in determining the potential of adverse visual impacts.

Visual Absorption Capability (VAC)

Visual Absorption Capability is a mapping technique used to estimate the ability of a landscape to absorb management activities such as timber harvesting, roading development, transmission corridors, or ski runs. The process allows resource managers to monitor the extent of visual change caused by management activities and provides a prediction of how difficult or easy it will be to meet prescribed resource management objectives. Just as the landscape's scenic conditions may significantly change within a relatively short distance, the landscape's ability to absorb management change may also differ.

This concept was introduced and developed in the Forest Service in the early 1970's. In the Alaska Region, with large and remote landscapes, it required an overlay mapping system that allowed landscape architects to provide timber harvest specialists with information concerning the expected level of adverse visual impact (Knode 1974). The idea was borrowed and refined from a study conducted on Martha's Vineyard in Massachusetts (Jacobs and Way 1969). In the Massachusetts study, landscape architects wanted to determine the acceptable level of housing and commercial development that could occur and still retain the unique visual character of the island. In Alaska, however, the developments were quite different--clearcutting, roads, and logging camps.

Another early approach utilized computer mapping of visible land and used the program called VIEWIT (Travis and others 1974). The program was applied to the Mineral King Visual Analysis (Johnson 1974)

to determine distance, aspect relative to the observer, and slope. All are important criteria in developing VAC maps.

In the mid-1970's, the initial concepts of VAC and VIEWIT were applied to a microcomputer program called Perspective Plot (Twito 1978). Case studies on the Kootenai National Forest (Tlusty 1979) found the use of microcomputers was less costly and more useable in developing absorption inventories.

As might be expected, the criteria used to map the landscape are usually modified to the different landscape regions and landscape developments. Most approaches, however, incorporate a combination of physical and perceptual factors (Anderson and others 1979) to determine a mapped rating of low, medium, or high ability to absorb a predetermined change to the landscape. The factors commonly considered include:

Physical Factors

slope
vegetative pattern
vegetative screening ability
site recoverability
soil color contrast
landscape diversity
land stability
water form diversity
soil erodability

Perceptual Factors

distance
number of times seen
number of viewers
duration of viewers
duration of view
focal point sensitivity
slope relative to observer
aspect relative to observer
lighting
season

The VAC process continues to be studied. Current technology and high public expectations allow complex measurements to be objectively displayed in graphic form with the potential for linking landscape measurements to the specifications for the visual quality requirements of Federal, State, and local standards (Iverson 1985). Also, a conceptual model developed for evaluating the visual impact of introduced land-use policy on the scenic resources of the Columbia River Gorge National Scenic Area could have utility in minimizing the adverse effects of the development within the corridor (Knode 1987).

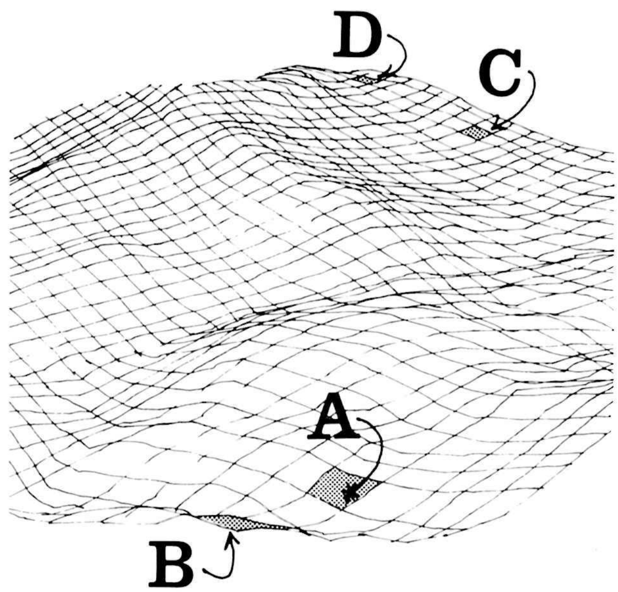


Figure 4--*All of the squares on this landscape are of equal size. When viewed from one observation point, it is apparent from a comparison of squares A through D that they appear to be quite different in the amount of surface area viewed; this illustrates the landscape's ability to absorb using distance, aspect, and slope criteria.*

Perspective Plot

Land managers and interested publics are always concerned about the visual change a management activity might cause to an existing landscape condition. Typically, the answer was not known until the activity was completed and viewers could "see" for themselves what visual change had taken place. When highly adverse visual impacts were the result, it generally was either too late, or very costly, to alter developments such as ski runs, clearcuts, transmission corridors, or road development. To a large extent, this need not occur if current techniques are used to "simulate" the activity before it is implemented. With computer graphics, an accurate "picture" can be constructed to depict how it will actually look before implementation.

Prior to the use of computer graphics, landscape architects and others used "free-hand" sketches, topographic models, and projections from topographic maps. In some especially critical areas, brightly colored balloons were tethered to represent the outline of a timber harvest unit. All of these efforts were costly and usually lacked the needed accuracy. In the mid-1970's, microcomputers were used to draw accurate "pictures" of proposed harvest units. The technique of Perspective Plot (Twito 1978) was developed into a fast and convenient means of examining the visual effects of management activities. This technique is widely used in the Forest Service and has been further developed (Nickerson 1980) to include simulation of most of the major activities that occur on national forest lands.

Corridor Viewsheds

A corridor viewshed is the total landscape seen from all, or a logical part, of a travel route, use area, or water body. In forest and resource land management planning, corridor viewsheds are those areas selected for intensive visual management. The plan will generally give direction as to desired future condition, adopted visual quality objectives, amount of harvest per decade, and so on. An implementation schedule for the plan should give more detail on how and where to retain or create the desired forest character in an attractive sequential arrangement over time and space. The schedule may further delineate the viewshed into foreground (fg), middle ground (mg), and background (bg).

An interdisciplinary team should reexamine the data from the forest planning records on plant community characteristics, timber stand factors, visual resource data including VAC and VMS, associated resource objectives, transportation and logging systems, and the forest residue situation. Additional data may be needed.

After careful analysis, a schedule of integrated project sets may be designed to achieve the desired visual character over time and space, within the biological potential, and coordinated with associated resource objectives.

Primitive and semiprimitive settings within viewsheds should also spatially locate areas to be managed. These settings may fall within middle ground and background zones of viewsheds, entirely outside, or a combination of both. It is imperative that any schedule of project sets for middle and background of viewsheds that also fall within these primitive or semiprimitive settings be designed to meet the more restrictive standards and guidelines--usually the primitive or semiprimitive criteria.

Vegetative Management in Recreation Settings

Setting Indicators

The setting indicators mentioned in the Recreation Opportunity Spectrum (ROS) section include three that are of direct concern when one is writing silvicultural prescriptions for specific settings. They include **visual quality** resulting from nonrecreation activities, **access** into and through the setting, and **recreation site modifications** due to silviculture activities. Indirectly, the indicators of remoteness, social encounters, and visitor impacts may also be affected by silvicultural activities. (See chapter 60 of the ROS Users Guide for more detail.)

Visual Quality--The key to managing the visual quality of each setting is to use a compatible visual quality objective and its corresponding guidelines. The visual quality objective describes varying degrees of allowable alteration of the characteristic landscape in each ROS setting. The desired visual character to be achieved in the future must also be determined for each setting.

Primitive--Vegetative management by timber harvest is generally not appropriate.

Semiprimitive--Limited vegetative management by timber harvest may be done for the purpose of enhancing the semiprimitive setting, and that will meet the compatible VQO. See also Access.

Roaded setting--Limited vegetative management by timber harvest may be done for the purpose of enhancing the semiprimitive setting, and that will meet the compatible VQO. See guidelines under the section entitled Conceptual Examples and in USDA Handbook 559 (USDA Forest Service 1980). See also the Access discussion that follows.

Access--Access includes the type and difficulty level of travelways in the setting. Changes in access influence both the levels and types of recreation use

an area receives. Improved access can lead to increased use, resources impacts, and an increased need for management action. Access affects the way in which some recreation experiences can be realized. For example, highly developed access can reduce opportunities for solitude, risk, and challenge; on the other hand, it promotes convenience and facilitates experiences associated with meeting and enjoying others.

Primitive and SPNM settings--Locate and design roads outside the settings to maintain or enhance feelings of remoteness from sights and sounds of human activity. Locate new trail heads and parking areas where they meet recreation objectives, including keeping social encounters and visitor impacts within acceptable limits.

SPM settings--Locate and design primitive roads to provide challenge to the off-road vehicle and trailbike users. Discourage highway vehicles. Primitive roads may also provide access to isolated dispersed camp sites, berry fields, wood gathering areas, and distant views.

Roaded settings (dispersed areas)--Locate and design roads to access but isolate recreation sites, maintain privacy or hiding cover around user sites, access desirable vistas, provide needed parking, and so forth.

Recreation Site Modifications--People are territorial. They form strong attachments to favorite and often-visited places and usually do not wish to see them changed. It is extremely important to identify the location of such sites before any on-the-ground management is done.

In all settings, any vegetative management in and immediately around recreation sites should be done to maintain or increase hiding cover. People want privacy and quiet, and they try to separate themselves from other parties and from evidence of other resource uses. This seems to be as true for people in moderately developed areas as it is for people who prefer wilderness. Such isolation can be provided with appropriate screening and/or by maintaining adequate distances between recreation sites and other types of forest uses. When managing roadsides for visual attractiveness, managers should be careful to avoid destroying hiding cover at nearby campsites.

"Edges" seem to influence recreational use. For example, sites near natural or artificial openings and riparian and coastal areas all appear to be used more frequently than other locations (Clark and Stankey 1979).

Visual Mitigation and Desired Visual Character

To implement silvicultural methods in an esthetically acceptable manner requires an understanding of the visual objectives and recreation setting needs. These broad resource objectives are usually developed into more detailed statements under two major categories--visual mitigation and desired visual character. Each has a different meaning and provides different levels of visual resource emphasis to a landscape activity such as timber harvesting or roadbuilding. They are, however, guided by the visual quality objectives and recreation direction established in the forest plan.

Visual Mitigation

This involves the use of techniques or practices that reduce potential adverse visual impacts. For example, visual mitigation techniques for clearcutting usually involve some, or all, of the following: shaping the harvest unit, controlling the size of the unit, establishing the distance between harvest units, and determining when the adjacent stand will be ready to harvest in a visually acceptable manner. In addition, the units may have practices in which individual trees (or groups of trees) are left for later harvesting, edges of the unit are "feathered," and logging slash can be burned or reduced to a low profile.

Since the 1960's, all of these techniques and practices have served to mitigate, or reduce, adverse impacts in which resource specialists attempt to emulate natural conditions as much as possible. This usually will not, however, enhance or improve the appearance of the landscape to a level that existed prior to harvesting. The use of Perspective Plot and VAC programs provide strong visual analysis capabilities to the concept of mitigation.

Research related to forest esthetics generally supports the following conditions as being least preferred. Often these adverse visual impacts can be reduced to acceptable levels through visual mitigation.

Least Preferred

- Artificial intrusions, especially:
  clearcuts,
  slash,
  stumps,
  other signs of timber harvesting disturbances, i.e., soil disturbance, machinery, gravel pits, highly developed logging roads.

- Plantations and "monocultures".

- Standing diseased, dead, or dying trees in large numbers.

- Dense "eye-level" vegetation or undergrowth; i.e., a thicket with dense sapling stands or dense forest understories over large areas.

Desired Visual Character

This concept requires a prescription, or statement, that maintains or visually improves the forested landscape appearance. It recognizes the landscape appearance as a resource that requires management considerations that typically go beyond visual mitigation.

The use of desired visual character prescriptions requires a full understanding of the biological requirements of various tree and shrub species and the public's visual expectation for the setting. Research related to forest esthetics generally supports the following as being the more preferred visual conditions of forested landscapes.

Most Preferred

- Natural or natural-appearing forested landscapes.

- Vegetative diversity, i.e., varying forest cover types, tree species, and mixed conifer-deciduous stands.

- Large-diameter trees, i.e., in a mature or old-growth forest setting with many large trees.

- A scattering of unusually formed, or "picturesque" trees.

- Open or sparse forest undergrowth, i.e., "parklike" contrasted against denser stands.

- Openings that provide views and vistas of interesting landscape features.

- Natural-appearing forest openings.

- Trees with visually interesting bark characteristics, e.g., paper birch or ponderosa pine.

- Trees or shrubs that provide fall color.

The concepts of mitigation and desired visual character may vary widely between different regions of the Forest Service and different tree species. There are, however, continuing efforts to further develop the concept by using new technology and research findings.

Almost all of the forest research related to visual mitigation and desired visual character has been conducted since 1970. These scientific findings, about esthetic perception of forests, generally relate to near-view situations, and the findings generally support the intuitively derived concepts previously used by landscape architects and forest resource managers (Ribe, in press).

Silvicultural Systems and Visual Management Systems

The basic objective of silviculture is to create a specific kind of vegetative character or condition to meet specific management objectives for a given area. In semiprimitive, roaded natural, or rural settings, where maintaining or enhancing visual quality, hiding cover for user sites, and so forth, are of major importance, silviculture may play a primary role in achieving the desired character. Ability to achieve visual quality objectives through applied silviculture varies depending upon management concepts used (even-aged versus uneven-aged management) and forest type adaptability to each management concept.

Using Uneven-aged Management

When applied to appropriate species, uneven-aged management produces forests that contain trees of

many sizes and ages intermixed in the same stand. The forest canopy remains relatively continuous and unbroken. As a result, visual impacts of timber management activities may be kept to a minimum; the uneven-aged system is capable of achieving the retention visual quality objective in all distance zones if it is properly applied.

Adaptability to uneven-aged management depends upon the species desired, their tolerance to shade, their place in the community's successional development towards climax, and on the environmental or microclimate conditions of the selected site.

Forest types that contain desirable or acceptable tolerant species can usually be handled under uneven-aged management. For example, northern hardwoods that include sugar maple and beech are generally adaptable to management with uneven-aged techniques. Eastern red spruce-balsam fir and Rocky Mountain Englemann spruce-subalpine fir types are also adaptable.

There are a few forest types dominated by shade-intolerant species that can be handled under uneven-aged management simply because more shade-tolerant species are absent or grow slowly. Many ponderosa pine forests in the Rocky Mountains and eastern Oregon and some mountain hemlock forests in the southern Oregon Cascades are examples.

Some shade-tolerant species that seem well adapted to uneven-aged techniques cannot be managed that way because partial cutting makes them susceptible to damage from such agents as windthrow or insect and disease infestations. The western hemlock-sitka spruce type is such an example.

Forest types dominated by shade-intolerant species, or types in which the intolerants are to be favored over the tolerants, usually cannot be managed using uneven-aged techniques--at least not without great difficulty and expense. Typical examples include coastal Douglas-fir, the southern pines, aspen-birch, oak-hickory, and northern hardwoods that are dominated by cherry, ash, yellow-poplar, and similar species.

In general, the more adaptable a timber type is to uneven-aged management, the easier it is to meet the more difficult visual quality objectives. It may be possible to meet a Retention visual quality objective with uneven-aged management using single tree selection cutting in situations where none of the traditional even-aged techniques would do so. Examples include: An observer wandering on foot through developed sites or along trails and looking at foreground landscapes from all angles; an observer with a long view duration scrutinizing a foreground landscape enclosed by landform; an observer viewing Class A landscape variety in a middle ground landscape for a long duration.

The advantage of uneven-aged management in these situations results because it is small scale, process-selective in nature, random in pattern, and because it leaves the natural appearing forest character intact when viewed from almost any angle. For these reasons, uneven-aged management should be considered in even the less adaptable types where visual quality objectives cannot be met by even-aged techniques.

Using Even-aged Management

In some forest types and microsite situations using uneven-aged management may not be a viable alternative. Under the section entitled "Conceptual examples..." are suggested modified even-aged management treatment concepts. Carefully applied, it should be possible to meet Retention and Partial Retention along less sensitive parts of viewsheds such as road and highway foregrounds and middle-grounds where the viewer is moving at a moderate rate of speed and not focusing on the landscape for a long period of time.

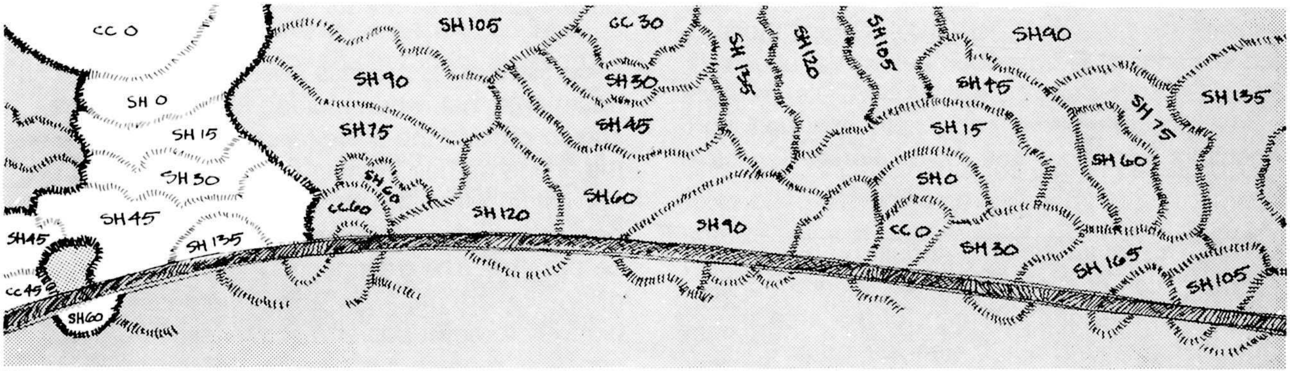
Conceptual Examples of Visual and Silvicultural Management

Treatment Concepts

Progressive small-scale entries are suggested to achieve the various VRM objectives. The designer of clearcut and shelterwood units must be concerned with scale and shape as well as number and arrangement of harvest units.

Initial entries should begin both at the road edge and along the back of the treatment area. Subsequent regeneration harvest entries should progress toward or away from the observer and be carried out sequentially (figure 5). The timing of entries should be controlled by the Visual Quality Objective, the

site productivity, and the ability of the previously regenerated stand to provide sufficient height and color differences in age classes to meet the small-scale variety objectives. The fire hazard and conditions requiring disposal of debris created by commercial or precommercial thinning should be physically treated or abated naturally prior to new entries.



Legend
CC = clearcut
SH = shelterwood
\# = year of entry

Figure 5--*Conceptualization of possible treatments to a 250-year-old Douglas-fir stand bordering a road.*

While the depth of the treatment area will vary, depending upon topography and the position of the observer, 245-365 m (800-1,200 ft) should generally be sufficient to meet all VQO's.

Units in the immediate foreground will logically be a combination of shelterwood and very small clearcuts. New units may be larger than the initial unit size, as long as only a small portion of new cutting is opened up to the observer.

Only the first three or four entry periods should be planned and recorded. This will set the pattern conceptually, but will allow future designers the flexibility needed to incorporate necessary changes as the landscape character evolves, technology advances, and the physical condition of the timber stand develops.

The selected example visualizes a harvest schedule designed to meet VQO's while systematically converting existing old-growth stands to thrifty, rapidly growing, even-aged small substands. These stands continue to grow until target size, bark characteristics, and other conditions are achieved.

First Entry--A clearcut and shelterwood are made at the backside of the treatment area, with the shelterwood toward the observer. Sufficient uncut area must remain between initial entries to permit progressive cuttings described in later entries.

After slash disposal, both the clearcut and shelterwood sites are planted to ensure prompt regeneration. This will begin to set up a transition zone to soften the visually harsh edge of Douglas-fir trunks.

Second Entry--The initial-entry shelter trees are removed and any blowdown is salvaged. A new shelterwood is made toward the observer. After slash disposal, the second entry cutting areas are planted while the first entry stands are precommercially thinned. Careful attention to density control should further soften unit edges, create diversity, and permit growth of the young stand at an acceptable rate.

Third, Fourth, and Fifth Entries--Third and fourth entries essentially repeat the previous treatments except that commercial thinning is carried out in the earliest regenerated stands that contain merchantable excess trees. The shelterwood unit will open out onto the road front in full view of the observer during the fourth entry. The fifth entry removes the shelter

trees at the road's edge. Primary guidance for this and the fourth entry can be found under each Visual Quality Objective on pages 167 and 168 and Landscape Design on pages 35 and 36 of Agriculture Handbook 559 (USDA Forest Service 1980).

Several variations of the aforementioned treatments are available to meet specific VQO's. One of these, termed "Retention," is described below. Variations for Partial Retention and Modification VQO's, as well as middle ground treatment concepts, may be found in Agriculture Handbook 559 (USDA Forest Service 1980).

Retention--The treatment area should be harvested by a combination of shelterwood and clearcut units, at a maximum rate of 10 percent of the area's commercial forest land per 15-year period or 6.7 percent per decade with units of appropriate size. One hundred fifty years will complete the harvest of the treatment area, but an additional 35 years will be necessary to meet the target mature tree diameter.

The initial entries at the back of the treatment area should consist of 1.2-2.0 ha (3-5 acre) clearcuts. Exact size of the clearcuts and accompanying shelterwood units will depend on landform configurations and how the site is seen from higher viewing points.

Clearcuts and shelterwoods at the road's edge should be located at nonfocal points: The length of road frontage should be approximately 46-91 m (150-300 ft), with shelterwoods utilizing the greater distance. Both shelterwood and clearcuts should be used, where acceptable, to add variety.

Harvest along a road frontage should not exceed 76 m/km (400 ft/mi) on each side of a road during the first 15-year period. This distance can be slowly increased to 114 m/km (600 ft/mi) during the last 15-year period of the 150-year conversion.

New cutting units should be located behind vegetative screens, above observer eye level, along high cut banks, or on the slope below observer eye level. Occasionally, they may be opened up to full observer view when they meet the requirement of "enhancement."

Vegetative screens may be used in several different ways. If ground vegetation exists along the roadside, it should be preserved. If there is no roadside vegetation, it may be created by planting semitolerant tree species 10 or 15 years in advance of the planned shelterwood. Shelterwoods can also be planned so that the greatest density of leave trees is located along the road.

Silvicultural Treatments

Each silvicultural process illustrates a series of stand treatments that, when molded to fit a given site, should provide the scale for regeneration activities, the timing of their entries, and the progression of harvesting within the site. This planning provides the basic parameters within which meeting VQO's should be possible. The treatments, when molded to fit a given site, are generally appropriate for road and highway foregrounds and semiprimitive settings. The concepts represent a summary of the full-scale treatments including middle ground found in Agriculture Handbook 559 (USDA Forest Service 1980). This handbook also contains landscape design treatments that not only influence the silvicultural alternatives but also provide the additional mitigation and enhancement techniques necessary to meet VQO's.

The following illustrate possible silviculture treatments designed to create or maintain certain visual characteristics in a given biological situation: for Douglas-fir, maintain a dominance of mature forest character and vegetative texture in a semitolerant, but difficult to manage visually, subclimax species; for lodgepole pine, convert an intolerant seral species (lodgepole) to a more manageable and visually attractive climax situation (Englemann spruce-subalpine fir, with some larch and lodgepole pine); for northern hardwoods, maintain older climax stands with areas of subclimax intolerant species for color and texture contrasts.

Douglas-fir--To illustrate foreground treatments in a Douglas-fir stand, a segment of road foreground with uniform stand characteristics was selected from a corridor plan.

The specific characteristics of the timber stand and area selected were:

1. A Douglas-fir stand with a relatively unbroken canopy.

2. An age that exceeds 250 years, but without serious insect or disease problems; stable.

3. Site index of approximately 44.2 m (145 ft) at base age 100 years.

4. Flat or gently rolling topography.

The goals were:

- Target mature tree diameter: 91 cm (36 in) average for Retention; 76 cm (30 in) average for Partial Retention.

- Unnatural edges should remain subordinate or not evident for Retention or Partial Retention objective.

- Allow colorful shrub and ground cover species to intermix with the seedlings and sapling age classes.

- Create small-scale areas of different age classes to provide variety while maintaining a dominant, mature stand characteristic.

The observer in the foreground is vehicle oriented, traveling at a rate of 56 to 80 km (35 to 50 mi) per hour. The middleground observer is above and about 0.6 km (1 mi) distant from the observed area.

Lodgepole Pine--A segment of roadside foreground with lodgepole pine was selected from a corridor plan to illustrate the conversion of an intolerant seral species to a more manageable and visually attractive climax stand. The concept is fully reported and illustrated in "Timber," Agriculture Handbook 559 (USDA 1980)).

The silvical characteristics of lodgepole pine in northern Idaho and western Montana include the need to manage by even-aged regeneration methods, the species' relatively short life of about 80 years, and the high susceptibility to insect infestation. The more prominent visual characteristics of lodgepole pine include extensive and almost pure stands of the same age that may create a visually monotonous foreground, lack of trees of large diameter or of those with interesting bark texture, and the need of even-aged regeneration that may create adverse visual conditions at the time of clearcutting.

The conceptual study illustrated the use of an existing stand of lodgepole pine, along with the habitat type. This is significant in that the existing stand could have been clearcut and regenerated to another stand of almost pure even-aged lodgepole pine. However, the habitat type classification system describes land of similar biotic potential and allows managers to visualize the vegetative development through all stages of plant succession. In this example, it meant managers could elect to stay with an early successional species--lodgepole pine--or work toward later succesional species--subalpine fir and Engelmann spruce and include some larch and lodgepole pine.

A visual inventory and analysis was conducted for the road corridor to determine the landscape features that provide visual opportunities and limitations. In addition, visual absorption capability (VAC) mapping was conducted for middle ground and background planning.

The visual quality objective, silvical characteristics, and the visual inventory and analysis were used to develop both specific visual mitigation and desired visual character requirements. For example, the following illustrates the visual prescription for the visual quality objective Foreground-Retention. This would, however, be different for Partial Retention or Modification.

	Immediate foreground	Remaining foreground
(a)	Surface-cut stumps.	
(b)	Complete activity debris treatment. Clean up so as to not be evident from the road.	Standard fuels management.
(c)	No evident visible ground disturbance after 1 year, as viewed from the ground.	

(d)	Natural-appearing tree spacing (irregular-spacing concepts).	
(e)	No strong "tree bole effect."	Same as immediate foreground.
(f)	Contrasting and diversified species from the road.	Same as immediate foreground.
(g)	Large-tree character--39.6 m (130 ft) high and +51 cm (+20 inch) diameter (hold larch as long as possible if crowns are good).	Same as immediate foreground.
(h)	Activities relate to small-scale design.	Same as immediate foreground.
(i)	Hold the optimum desired character for as long as biologically possible--140 years or more.	Same as immediate foreground.
(j)	A forested landscape character is required in the foreground to meet the VQO.	Same as immediate foreground.
(k)	The foreground will require five harvest entries, with 2.8-3.2 ha (7-8 acres) harvested each entry. Clearcut size will average about 0.8 ha (2 acres) in size.	

The silvicultural treatments needed to achieve the visual and timber objectives were extensive and covered the major forest practices for approximately 200 years. Figure 6 illustrates the major biological and visual changes over the management period. Even with intensive management practices it may not be possible to meet the VQO of Retention during all management phases. However, once the stand is converted and established, it will sustain the desired visual characteristics for an extended period. As might be expected, the VQO's of partial Retention and Modification would be easier to maintain but would not provide the high levels of scenic quality.

Northern Hardwoods--Major forest stands of northern hardwoods extend from the Lake States across the northern Appalachians and into New England. These stands usually contain an attractive mixture of species, ages, and heights. Most visitors visually appreciate these landscapes when they present a condition of an unbroken forest, with a high percentage of larger trees. Their fall color is without equal in providing visually stimulating conditions. Treatment guides have been developed (USDA Forest Service 1980) for a wide range of conditions that either develop or maintain a desired visual condition, along with techniques to mitigate adverse visual impacts. The guides, however, are not intended to be fixed requirements but are intended to stimulate site-related creativity. The range of timber harvest treatments may include: single tree selection; group selection; clearcutting; shelterwood cutting; two-age management; and thinning. Figure 7 illustrates the range of harvest treatments that might exist along a road corridor.

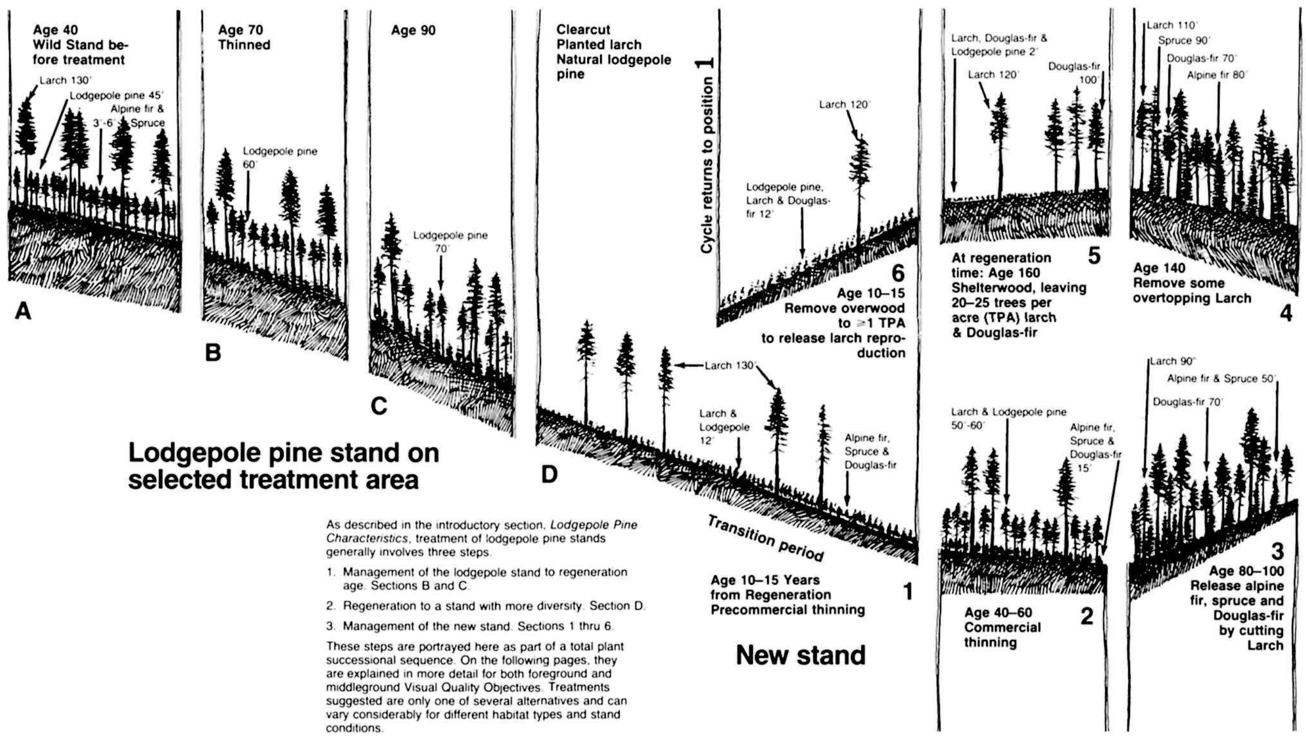


Figure 6--*Management of the lodgepole pine stand.*

A project-level visual prescription process is needed to assist in determining which among several timber harvest treatments is the most appropriate. Two hardwood stands are used to illustrate the different silvicultural practices needed to maintain high levels of visual quality and continued timber harvesting.

70-year old paper birch stand--The site is of good quality for pioneer species such as paper birch or aspen, or for climax species with sugar maple and asociated species. The silvicultural prescription objective is to maximize timber resource outputs consistent with meeting the VQO of Retention and maintaining the desired visual condition of a paper birch stand. The silvicultural prescription includes replacing the mature paper birch while maintaining a continuous "mature birch character" over some portion of the foreground.

Sugar maple stand with some basswood and yellow birch--The total basal area is 27.6 m²/ha (120 ft²/acre), with an average d.b.h. of 41-46 cm (16-18 in) with some trees up to 76 cm (30 in) in d.b.h.. The silvicultural objective of this stand is to maintain the desired large tree character of sugar maple, develop a less visually dense understory, meet the VQO of Retention, and have economic timber resource outputs.

The visual inventory and analysis was conducted prior to developing a silvicultural prescription for each stand. It included the following:

Recreation opportunity spectrum--In this example, it was roaded natural; driving activities related to a campground, summer homes, and non-destination driving; a hiking and cross-country ski trail crossed the study area.

Viewshed corridor--The two stands are part of an overall viewshed that included the entire corridor.

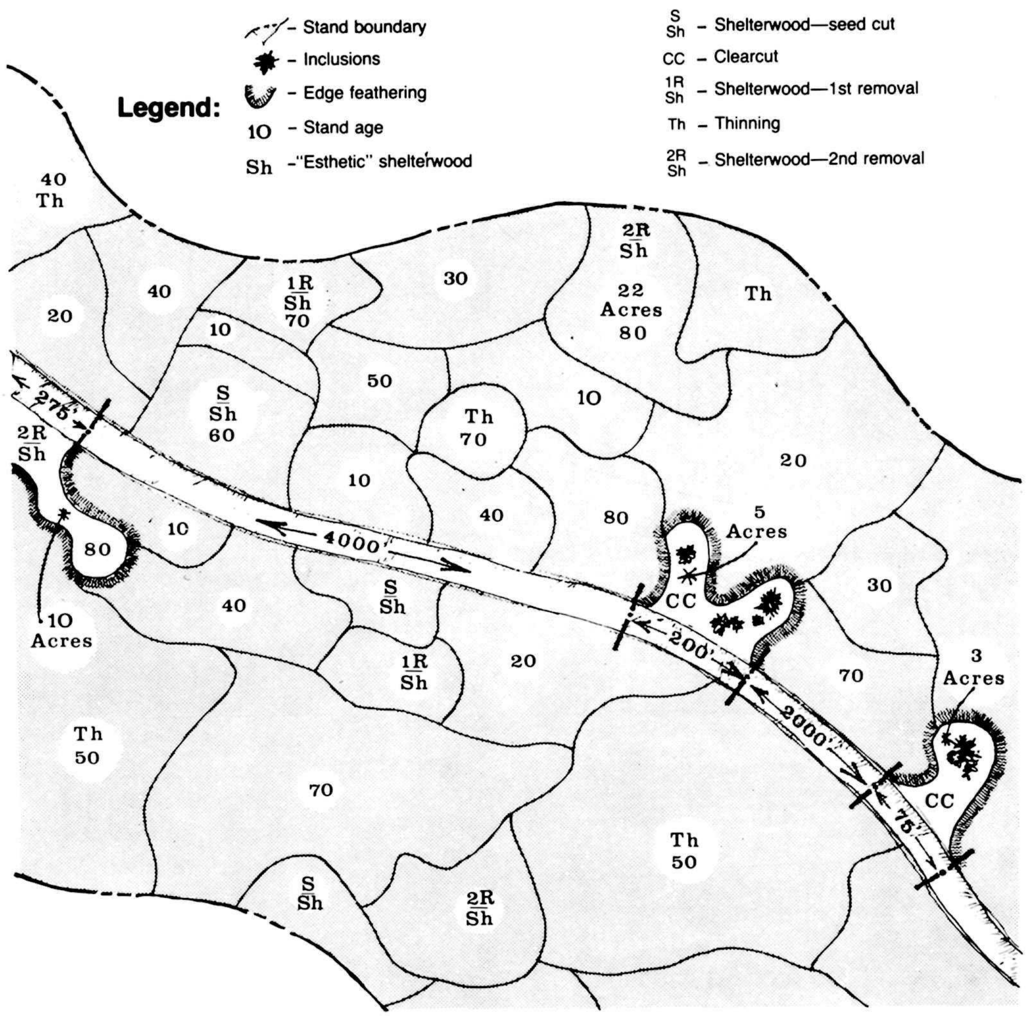


Figure 7--*Many treatment options exist for northern hardwoods. Each site requires careful study to determine the appropriate treatment to meet all resource management objectives.*

Visual Resource Prescription

VQO Retention--In general, this means man's activities would not be evident to the casual forest visitor and the activities may only repeat form, line, color, and texture that are frequently found in the characteristic landscape.

Existing Visual Condition--A low-speed forest road has foreground views of mature paper birch, large sugar maple, and some tree canopy over the entire road; the entire site presents an appearance of "naturalness." A trail crosses the birch and sugar maple stand.

Desired Visual Character--The major long-term desired visual character is the condition that currently exists. In addition, the introduction of coniferous species for winter diversity and a less dense understory for added visual penetration during summer months are also desirable.

Visual Management Direction--

- Maintain or increase the spatial effects that provide "distant" foreground views into the stand and reveal subtle topographic changes.

- Maintain or increase the canopy effect over the road.

- Restrict right-of-way management that would encourage overstocked roadside vegetation and restrict views into the forest.

- Move the paper birch stand towards replacement while maintaining a continous white birch character over some portion of the viewed foreground.

- Maintain the appearance of a mature forest with large tree character.

- Retain roadside tree and shrub species that prove leaf color/texture contrast or noticeable flower characteristics.

- Introduce coniferous species in the area adjacent to the cross-country ski trail for winter vegetative contrast.

- Retain intervisibility between the cross-country skier and road users at the trail/road intersection.

- Restrict the development of logging roads off the main forest road when other realistic options exist.

- Have logging slash treatment conform to the VQO of Retention.

Specific Desired Visual Character Criteria--

- In the immediate foreground (about 76 m [250 ft]) of the sugar maple and hemlock stands, maintain through all phases 20 or more trees/ha (8 or more/acre) in the 56-76 cm (22-30 in) diameter class.

- Favor sugar maple hardwoods for large tree diameter.

- In the remaining foreground (about-to 183 m [250-600 ft]), maintain 10 trees/ha (4/acre) in the 56-76 cm (22-30 in) diameter class.

- Maintain the abrupt "pocket" of pure paper birch, and in other paper birch stands maintain a condition of some white bark character as viewed from the road.

- As a minimum, maintain an 80-percent canopy cover over the road to create a canopy tunnel effect through the maple stands.

- Manage the vegetation adjacent to the roadside, including the canopy over the road, in a manner that will provide a minimum of three areas with hardwoods in leaf that will enable visual penetration into the stands for a distance of 60 m (200 ft) or more.

- Provisions will be required to allow some scattered coniferous trees and some understory species to exist. If natural regeneration practices are not possible, plant about 49 trees/ha (20/acre) within 30 m (100 ft) of the trail and roadside.

- Directly adjacent to the road, maintain cherry and soft maple trees for flowering and fall color.

Visual Mitigation Techniques--

- Winter logging along road foreground.

- Summer logging along cross-trail foreground.

- High levels of logging slash reduction.

- Logging equipment that creates low site damage to trees and minimum soil disturbance except where scarification is needed.

- Establish logging landings and skid trails away from the main forest road.

- If group selection or clearcutting practices are needed, reduce the opening size to 1.2 hectares (3 acres) or less and with irregular shapes.

This visual information was used by the silviculturist along with existing birch and maple stand data to write detailed silvicultural prescriptions for a landscape management training program (Tlusty 1981). The silvicultural prescription for the paper birch stand included dividing the stand into three smaller units, site scarification for birch regeneration, a shelterwood first cut which removed about 20 to 30 percent of the crown cover, and planting 62 white pine trees/ha (25/acre). A second removal harvest would be conducted in 3-8 years or when the young birch understory was adequately established. This second "shelterwood" harvest would remove about 50 percent of the remaining mature paper birch. The remaining mature birch would be allowed to reach biological maturity, which could mean that these trees would live to about 200 years and possibly never be harvested. This would allow the stand to maintain the desired visual character goal of "maintaining a

continuous white birch character over some portion of the viewed foreground."

The sugar maple stand was prescribed to be treated with individual tree selection harvesting. However, the "regular" harvesting treatment was adjusted to provide a greater number of large trees in the 38-48 and 51-61 cm (15-19 in and 20-24 in) size class. This would not only provide the needed large tree character, but allow for increased visual penetration into the sugar maple stand.

Summary

While silvicultural practices are approaching 100 years of guiding forest management, the innovative developments in visual resource and recreation practices have generally occurred in the past 20 years. In response to public interest, these developments include: design and planning strategies, legislative mandates, computer technology, and social research findings. Refinement of these developments will continue to improve the integration of the design arts with the biological and social sciences, providing the public with high levels of visual quality management in the Nation's national forests.

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Effects of Timber Management Practices on Insects and Diseases

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Introduction

Forests are dynamic and ever changing. They have been present on the Earth for eons--growing, developing, maturing, being destroyed, then replenishing themselves to start the process anew. Natural catastrophic events played an important role in this process. Fires, insects, and diseases eliminated and recycled the old and prepared the way for the new. In recent decades, human needs for goods and services from the forest led the way for major efforts in forest protection--we no longer consider it acceptable to have thousands of acres destroyed by fire, entire landscapes defoliated or killed by insect pests, or tree species like the American chestnut virtually eliminated by disease organisms. Our good intentions have resulted in hundreds of thousands of acres of physiologically mature forests that are "ready" for change. Pest outbreaks that are now occurring in these pathologically mature areas are effective indicators of forest condition. In other cases, modern management practices have contributed to increased forest susceptibility in quite different ways. Again through good intentions of providing goods and services from, and extending the productivity of, forest land, thousands of hectares (acres) have been planted on sites that are marginally suitable. In many cases, these efforts have resulted in huge blocks of densely-stocked, single-species, even-aged stands of high value, which are at high risk for pest attack and significant economic loss.

Properly timed stand treatments provide a balance for setting back the pace of natural succession and for reducing risk and damage from pests in intensively managed forests. This section addresses the major insects and diseases threatening the forests of the five ecographic regions of the United States, and the positive and negative influences that silvicultural treatments may have on the occurrence and severity of outbreaks of these pests.

Pest management considerations should become an integral part of integrated resource management planning. This planning should begin by carefully considering four basic questions:

1) What pests threaten at the various developmental stages of a given stand?
2) What short- and long-term impacts will the pest(s) have on the stand?
3) How does the stand (in terms of composition, structure, and vigor) influence the present and future dynamics of the pest organism(s)? and
4) Are there positive or negative effects of one pest (or treatment of that pest) on other pests?

These considerations are discussed in the sections that follow for each of the five ecological regions addressed in this report--first describing the major pests (or pest complexes), then describing relationships between common silvicultural practices and the severity of losses resulting from damage caused by these pests.

Southern Pines

Southern pine forests have long been ravaged by an array of insect and disease organisms that seriously affect their productive capacity. Each year, these organisms kill an estimated 28.3 million m^3 (1 billion ft^3) of timber, much of which is never utilized, and cause additional unmeasured losses resulting from growth reduction and quality degrade. The major pests affecting southern pines are listed in table 1, and are briefly described in the following sections.

Table 1--*Common and scientific names of major insect and disease pests affecting southern pine forests*

Reproduction weevils:	
Pales weevil	*Hylobius pales*
Pitch eating weevil	*Pachylobius picivorus*
Brown spot needle blight	*Scirrhia acicola*
Nantucket pine tip moth	*Rhyacionia frustrana*
Fusiform rust	*Cronartium quercum* f. sp. *fusiforme*
Pine bark beetles:	
Southern pine beetle	*Dendroctonus frontalis*
Black turpentine beetle	*D. terebrans*
Ips engraver beetles	*Ips avulsus*
	I. grandicollis
	I. calligraphus
Annosus root rot	*Heterobasidion annosum*
Littleleaf disease	*Phytophthora cinnamomi*

Major Pests

Reproduction Weevils--Adult reproduction weevils are attracted to fresh pine stumps, feed on young seedlings in the vicinity, and deposit their eggs in the large roots of stumps. Offspring that emerge from the roots also feed on the bark of young seedlings and often kill 20 to 30 percent of pine seedlings planted in cut-over, storm-damaged, burned, or otherwise disturbed areas. Mortality may range as high as 60 percent in localized areas. All southern pine species are susceptible to damage. Damage is most severe during February through June and less so in late summer and early fall.

Brown Spot Needle Blight--This blight occurs in all the coastal States from Virginia to Texas, and inland to Arkansas and Tennessee. All southern pines are attacked by the fungus, but only longleaf pine (*Pinus palustris*) seedlings are seriously damaged. Seedlings that are heavily infected can remain in the grass stage for several years and eventually die.

Pine Tip Moths--These moths deposit their eggs in the buds of young loblolly (*Pinus taeda*) and shortleaf (*P. echinata*) pines. Larvae developing in the buds cause tip and terminal mortality. Heavy attacks by multiple generations each year can stunt trees for up to 5-6 years. Severe recurring infestations can

cause significant reduction in height growth and long-term volume losses.

Southern Pine Bark Beetles--These are the most destructive insects affecting southern pines. There are three major pine bark beetles, or beetle groups. These are the southern pine beetle, the black turpentine beetle, and three species of *Ips* engraver beetles. All five species occur throughout the southern pine range. More than one of these species frequently occur in the same host tree and attack by one may predispose the tree to attack by another. Greatest losses occur in loblolly and shortleaf pine stands, although most of the native Southern pines are attacked.

Fusiform Rust--This rust is most common in loblolly and slash (*Pinus elliottii*) pines, but the other pine species may also become infected. Stem and branch galls caused by the fusiform rust fungus appear on all growth stages of infected pines, from seedlings to mature trees. Oaks (*Quercus* spp.), which serve as alternate hosts, are required for spread of the disease. Economic loss results from the death of trees (primarily younger seedlings), breakage of the stem at the gall, or reduction of sawtimber quality in trees not killed outright.

Annosus Root Rot--This rot is primarily a problem in thinned pine stands on well-drained soils with deep A-horizons with high sand content. Infected trees begin to die within 2-3 years after thinning. Additional mortality may occur for several years. Trees that survive in spite of infection may have reduced growth and are more susceptible to windthrow and bark beetle attack.

Littleleaf Disease--This disease most commonly affects shortleaf and, to a lesser extent, loblolly pines growing on low-quality sites. The disease rarely affects trees younger than 20 years of age and becomes increasingly severe in older, shortleaf pine stands in the Piedmont region. Future risk of infection can be determined by evaluating the site for signs of severe erosion, poor drainage, a shallow permeable layer, and early symptoms of littleleaf infection.

Silvicultural Practices

Much of the damage caused by these insect and disease pests can be prevented or reduced by properly scheduled silvicultural treatments. At the same time, however, consideration should be given to potential aggravation effects that treatment of one pest may have on others. Some of these relationships are described below.

Clearcutting--Regeneration of pine stands in clearcut areas is obtained through natural or direct seeding, or more commonly through planting. The major pests of direct concern during early stages of seedling establishment and development are pine tip moths, reproduction weevils, and fusiform rust.

The large number of stumps created during clearcutting operations provide increased attraction to adult reproduction weevils. Damage can generally be reduced to acceptable levels by delaying planting for one season after cutting to allow stumps to deteriorate and populations to subside. If planting delays are not possible, in-field sprays either before or after planting may be required.

Sites that have a history of high fusiform rust infection or sites on which future levels of infection might be expected to be high should be planted with rust-resistant seedlings or with seed from resistant geographic seed sources. Cultural practices that encourage branching, rapid growth, or otherwise result in an abundance of succulent young tissue should be discouraged. Site preparation should be minimized, fertilization delayed until age 8-10 years, and prescribed burning delayed until age 8 years or later. Risk of infection can be reduced by removing alternate-host oaks in or near the regeneration area. Losses can be offset in areas where projected future losses are high by increasing planting densities to allow for early mortality. Managers should at the same time, however, be aware of the possible conflicts between this practice and other recommendations that call for reducing stocking density to decrease future susceptibility and damage to both annosus root rot and southern pine beetle attack. The appropriate course of action will depend on management objectives, rotation length, geographic area, and site hazard.

Heavy attacks by multiple generations of pine tip moths in replanted clearcut sites can reduce growth rates of loblolly and shortleaf pines for the first 5-8 years of stand development. However, studies have shown that only those pines growing on the poorest sites suffer significant volume loss over a rotation.

Southern pine beetles and annosus root rot are of little concern in the early life of a stand established

in clear-cut areas. But future risk may be high because of stocking densities, needs for intermediate stand treatments, and projected stand values. Southern pine beetle risk can be reduced by improving drainage of low-lying sites in the Coastal Plain regions and by protecting sensitive sites during site preparation in the erosion-prone Piedmont. Where management objectives permit, mixed pine or pine-hardwood stands should be favored since they are less susceptible to beetle infestation. The threat from annosus root rot can be reduced by increasing initial spacing of seedlings planted on high-hazard sites. Wider spacing will delay the need for future thinning and will reduce root contacts through which the disease spreads. Where practical, pine species (such as longleaf) or hardwoods that are more resistant to annosus root rot may be considered.

Sites that are high hazard for littleleaf disease (or that have a previous history of the disease) should be regenerated with seed or seedlings from a seed source of shortleaf or loblolly pine that exhibits disease resistance, or with nonhost species such as longleaf pines or hardwoods. Areas that have been clearcut may also be considered for subsoiling or other drainage improvement operations where high-clay content, heavily eroded soils present high risk to littleleaf disease development.

Shelterwood--The shelterwood system provides natural regeneration and an opportunity to improve the composition and vigor of the older stand. Natural seedlings are generally less vulnerable to attack by reproduction weevils, probably because of thinner bark, reduced food base, and development under the overstory canopy. Pine tip moth damage is less severe because the treatment favors heavy ground cover and close tree spacing. Fusiform rust incidence may be high in shelterwood managed areas, but may be reduced by removing rust infected older trees to provide rust free or rust resistant overstory trees from which the new stand will develop. Damage from littleleaf disease may be reduced by making tree removal cuts early and frequently to maintain stand vigor. Early removal also recovers value from diseased trees and offers an opportunity to remove high-risk trees with increased susceptibility to other insect and disease organisms.

Shelterwood management is well suited for maintenance of high vigor stands of reduced susceptibility to bark beetles. Tree removal selections should be made to maintain stand basal area below 23.0 m^2/ha (100 ft^2/acre), and to remove high-risk individual trees such as those that have been struck by lightning, damaged in logging, or show rust or root rot symptoms. Where management objectives allow, species mixtures favoring hardwoods will reduce overall stand susceptibility to bark beetles. Care should be given to preventing buildup of logging residue and to not allow residue to remain in piles near residual crop trees, and to avoid making basal scars during logging, which increase risk to black turpentine attack.

Stumps created during the shelterwood operation should be treated with borax if the stand is not currently infected by the annosus root rot fungus, or treated with *Phelibia gigantea* if the disease is present. Shortleaf pine stands on high-hazard littleleaf sites should be maintained on short rotation cycles and should receive early and frequent intermediate thinnings.

Seed Tree--Fusiform rust and pine tip moths may affect regeneration in areas managed under the seed tree system; however, high stocking densities resulting from seed tree regeneration will generally tolerate the higher mortality levels. Fusiform rust infection may be reduced by removing severely infected pines and oak alternate hosts and thereby reducing the potential for infection of younger trees in the same or adjacent stands. Annosus root rot is generally not a problem in naturally regenerated stands.

Pine bark beetles may be a problem in residual seed trees, and later as dense regeneration develops into an older stand. Logging damage to seed trees may result in increased attack by black turpentine beetles. Logging residue offers opportunity for buildup of *Ips* engraver beetles. To prevent a buildup, the residue should be removed or distributed to allow for rapid drying. Developing stands may become susceptible to bark beetle attack as competition increases and vigor declines.

Group Selection--Damage by insects affecting young stands, such as reproduction weevils, will be less severe than under systems requiring extensive site preparation. Reproduction weevil and pine tip moth damage may also be less severe because there are not large quantities of host material available in which large populations can build. Fusiform rust incidence may be high because of microclimatic influences within small openings created by tree removal and

by accelerated terminal and lateral growth of trees in young stands following release.

Reduction of stand density will reduce susceptibility to pine bark beetles, but tree and site damage may increase risk under certain conditions. The extent to which treatment reduces risk or creates additional hazards depends upon care exercised during the operation, the size of tree groups removed, the size and density of untreated areas, and the pine/hardwood composition of the remaining stand. Site hazard to annosus root rot should be evaluated and stumps should be treated with borax when warranted.

Group selection may provide some beneficial effect in stands infected by littleleaf disease by increasing vigor of remaining trees. Individual tree mortality can be reduced by removal of infected and declining trees during cutting operations. In stands with less than 10-percent infection, diseased trees should be removed every 10 years; between 10- and 25-percent infection, every 6 years; and with greater than 25-percent infection, all shortleaf pines should be removed as they become merchantable and before disease symptoms become too severe.

Single Tree Selection--Openings created by removal of individual trees through single tree selection may produce microclimatic conditions that favor rust infection on young seedlings, particularly in stands where there is an abundance of oak alternate hosts. Other young-stand pests such as reproduction weevils, brownspot needle blight, and pine tip moths are rarely problems in areas naturally regenerated by selection methods because of regeneration density and presence of an overstory canopy.

As stands develop, they may be affected by fusiform rust, bark beetles, root rots, and interactions among these pests. Trees that are galled by fusiform rust are subject to breakage by wind and ice and may be infection courts for other insect and disease organisms. Single tree selection offers an opportunity to sanitize stands through infected tree removal. Removals should be made prior to prescribed burning, if it is planned, because trees with fusiform rust galls are more susceptible to fire-caused mortality, and charred cankers contaminate pulp. Annosus root rot problems may be intensified by selection removals on high-risk sites when stump surfaces are exposed to windblown spores. Damage caused by pine bark beetles is most severe in densly stocked stands with slow radial growth. Removal of selected trees that maintain basal areas below 23 m^2/ha (100 ft^2/acre) can be beneficial in maintaining vigorous tree growth. High-risk trees that may be slower growing or damaged by lightning, wind, ice, or other wounding agents should be given higher priority for selection. Caution should be exercised during summer cutting operations to avoid buildups by *Ips* engraver beetle and to prevent piling of logging residue, especially near residual crop trees. When management objectives allow, bark beetle risk can also be reduced by favoring species mixtures containing hardwoods. Damage by little leaf disease may be reduced on high-hazard sites by selectively removing obviously diseased trees. This is especially true where fewer than 25 percent of the stems are infected and/or where the residual stand will be inadequately stocked.

Pacific Coast Conifers

The Pacific coast region contains one of the largest areas of managed forests in the world. Good growing conditions, large volumes per unit area, large ownerships, (individual, corporate, and government), and extensive forests of desirable tree species contribute to the acreage under management. Silvicultural treatments are commonplace.

Insects and diseases cause significant losses in Pacific coast coniferous forests, but unlike in many other regions of the United States, the number of different pests is small. In the last 10-20 years, Pacific coast conifer stands have not experienced major defoliator or bark beetle outbreaks (with the exception of Douglas-fir bark beetle), and many diseases common in the inland western regions are not important in Pacific coast stands. Major insects and diseases of this region are listed in table 2 and are described briefly in the following sections.

Diseases of this region are listed in table 2 and are described briefly in the following sections.

Table 2--*Common and scientific names of major insect and disease pests of Pacific coast conifers*

Stem decays	Various fungi
Root diseases	
Laminated root rot	*Phellinus weirii*
Armillaria root rot	*Armillaria spp.*
Dwarf mistletoes	
Hemlock dwarf mistletoe	*Arceuthobium tsugense*
Douglas-fir dwarf mistletoe	*A. douglasii*
White pine blister rust	*Cronartium ribicola*
Douglas-fir bark beetle	*Dendroctonus pseudotsugae*

Major Pests

Stem Decays--Many different fungi are responsible for stem decays, and collectively they cause more volume loss than any other pest group affecting Pacific coast conifers. Losses caused by stem decays are steadily declining as mature and overmature forests are regenerated.

Root Diseases--The two most important root diseases of Pacific coast conifers are laminated root rot, caused by *Phellinus weirii*, and armillaria root disease, caused by *Armillaria obscura*. Many tree species are affected, but damage is most widespread in Douglas-fir stands. Damage caused by root diseases is increasing.

Dwarf Mistletoes--The most common species of dwarf mistletoes affecting Pacific coast conifers are hemlock dwarf mistletoe and Douglas-fir dwarf mistletoe. Some species of pines and true firs in northern California and southwestern Oregon are infected by dwarf mistletoes. Losses caused by dwarf mistletoes are declining sharply.

White Pine Blister Rust--White pine blister rust is still the most serious threat to western white pine and sugar pine. Losses to this disease are declining because the most susceptible trees have been killed and the survivors have more resistance.

Douglas-fir Bark Beetle--Douglas-fir bark beetle is the most significant insect affecting Pacific coast conifers. It is found only on Douglas-fir. Losses caused by this insect are diminishing, but occasional outbreaks still occur following large storms and fires.

Other--In addition to the above and other insect and disease pests, abiotic factors are playing a continuing and increasing role in the health of Pacific coast conifers. Storms, especially those accompanied by large amounts of precipitation and strong winds, are responsible for enormous volumes of windthrown timber. Air pollution is a factor, but has not as yet caused extensive injury to Pacific coast conifers because of proximity to strong onshore winds of the Pacific Ocean.

Silvicultural Practices

With few exceptions, the major forest insect and disease problems of Pacific coast conifer stands are dealt with by silvicultural treatments rather than with pesticides. Losses from the major insects and diseases affecting Pacific coast conifers are greater in unmanaged stands than those where any of the five silvicultural systems are being diligently applied. The effectiveness in altering stand risk to insects and diseases varies with the specific pests and

silvicultural system being used. These relationships are summarized in the section that follows.

Clearcutting--Clearcutting has the best potential for reducing pest-caused losses. Because all trees are removed, there is less opportunity to leave pest-affected trees than with other systems. Clearcutting provides the best opportunity for managing root disease of Pacific coast conifers because tree species that are less susceptible can be planted in the cleared areas; also, infection centers can be accurately located and defined, and infected stumps that introduce infection into future stands can be removed following clearcutting. And, if done correctly so no dwarf mistletoe-infected residuals or infected trees are left on the edges of the openings, clearcutting can result in local eradication of this group of pests.

Shelterwood and Seed Tree--These two silvicultural systems have lower potential for perpetuating insect and disease problems than the selection systems. The greatest risks associated with shelterwood and seed tree cuts are from stem decays and dwarf mistletoes. Overstory trees should be removed soon after regeneration is successfully established to prevent excessive physical damage to the small trees from logging. Dwarf mistletoe-infected trees should not be left to provide seeds or shade for the regenerating stand and should be removed before the regeneration reaches 0.9 m (3 ft) tall to minimize infection of the susceptible seedlings. Douglas-fir bark beetles can build up in windthrown trees, and thus care should be taken with shelterwood, seed tree, and clearcuts to place boundaries of cutting units in locations where windthrow of edge trees will be minimized.

Single Tree Selection--Single tree selection has the greatest potential of all silvicultural systems to increase or maintain high risk to the major insects and diseases affecting Pacific coast conifer stands. Practically all stem decay is initiated with wounds on trees. Single tree selection results in a high degree of tree wounding because of the number of stand entries and limited maneuvering room for equipment associated with this approach. Most of the tree species that regenerate naturally in single tree selection systems, such as hemlocks and true firs, are also those that are most damaged by stem decays. Trees with stem decays or large wounds could be removed during subsequent single tree selection entries.

Root diseases may also be perpetuated through single tree-selection because infected, but nonsymptomatic, trees are more likely to be left than with other silvicultural approaches. Wounding during stand entries also makes trees and stands more subject to damage from Armillaria root disease and annosus root and butt rot.

Selection systems that create multiple canopy levels have the greatest potential for perpetuating dwarf mistletoe infestations. It is difficult to successfully practice single tree and group tree selection in stands with widespread dwarf mistletoe, particularly if openings created by tree harvesting are large enough to encourage regeneration of susceptible species.

Group Selection--Group selection has less potential of increasing susceptibility to insects and diseases than single tree selection, but removal of many small groups of trees can result in many of the same root disease, stem decay, and dwarf mistletoe problems. The potential for damage should decrease as the size of the tree groups removed increases. On the other hand, removing groups of trees affected by stem decays, dwarf mistletoes, and root diseases can also improve overall stand condition. Dwarf mistletoes can also be a continuing problem in group tree selection areas because infected trees are often left, and the system generally results in a multicanopy structure that exacerbates mistletoe spread.

Single tree and group selection systems have good potential for preventing outbreaks of Douglas-fir bark beetles. Under these systems, infested trees can be quickly salvaged before the beetles have the opportunity to spread to adjacent trees. This can be done without harvesting the entire stand.

Other Stand Management Practices--Precommercial thinning is a common practice in Pacific coast conifer stands. Susceptibility to Armillaria root disease can be lowered by thinning to avoid stress from overstocking. Care should be taken during precommercial thinning activities to avoid wounding crop trees. Similarly, thinning provides an opportunity to favor tree species that are less susceptible to organisms that cause stem decays. Dwarf mistletoes can be reduced by combining stand cleaning with thinning.

Planting provides an opportunity to reforest sites with tree species that are not susceptible to root pathogens and dwarf mistletoes that may be on a site. Similarly, planting of rust-resistant western white

pine (*Pinus monticola*) and sugar pine (*P. lambertiana*) seedlings is the most effective method of preventing losses to white pine blister rust on sites where damage from this disease has been common in the past.

Pruning is not commonly practiced in Pacific coast conifer stands; however, if it is done properly, it can effectively reduce damage caused by stem decays, dwarf mistletoes, and white pine blister rust. In the case of white pine blister rust, cankered branches and lower crown branches (where lethal tree infections are most likely to occur) are removed. Pruning is usually done in combination with thinning.

Western Inland Conifers

Ponderosa pine (*Pinus ponderosa*), lodgepole pine (*P. contorta*), western white pine, larch (*Larix* spp.), Douglas-fir (*Pseudotsuga menziesii*), grand fir (*Abies grandis*), white fir (*A. concolor*), red fir (*A. magnifica*), and Englemann spruce (*Picea engelmannii*) are the most important western inland conifers. These tree species are plagued by a large number of insect and disease pests, and large outbreaks are relatively common. The most important groups of insects and diseases are presented in table 3.

Table 3--*Common and scientific names of the most important insects and diseases affecting western inland conifers*

Stem decays	Various fungi
Root diseases:	
Laminated root rot	*Phellinus weirii*
Armillaria root rot	*Armillaria* spp.
Annosus root rot	*Heterobasidion annosum*
Dwarf mistletoes:	
Western dwarf mistletoe	*Arceuthobium campylopodum*
Lodgepole pine dwarf mistletoe	*A. americianum*
White pine blister rust	*Cronartium ribicola*
Hard pine rusts:	
Western gall rust	*Endocronartium harknessii*
Comandra blister rust	*Cronartium comandrae*
Western spruce budworm	*Choristoneura occidentalis*
Douglas-fir tussock moth	*Orgyia pseudotsugata*
Bark beetles:	
Mountain pine beetle	*Dendroctonus ponderosae*
Western pine beetle	*D. brevicomis*
Douglas-fir bark beetle	*D. pseudotsugae*
Spruce beetle	*D. rufipennis*

Major Pests

Stem Decays--True firs (*Abies* spp.) and spruces (*Picea* spp.), in particular, suffer large volume losses from stem decays. Pines, Douglas-fir, and larch are affected, but to a lesser extent. Many different fungi are responsible. Losses from stem decays are steadily declining as more western inland conifer stands come under management, and as overmature stands are regenerated.

Root Diseases--Laminated root rot, armillaria root disease, and annosus root and butt disease are the most important root diseases of western inland conifers. Root disease incidence and damage appear to be steadily increasing.

Dwarf Mistletoes--Vast areas of western inland conifer stands are infested by dwarf mistletoes. Most tree species are affected, but ponderosa pine, lodgepole pine, Douglas-fir, and larch are most seriously impacted. The area infested by dwarf mistletoes is slowly declining.

White Pine Blister Rust--This disease is the greatest threat to western white pine and other five-needle pines. It occurs over almost the entire range of western white pine. Losses from blister rust are declining.

Hard Pine Rusts--Western gall rust and commandra blister rust are the most damaging rusts of two- and three-needle pines. These rust fungi cause galls and cankers, resulting in growth loss, deformities, top-kill, and tree mortality. Losses from these diseases may be declining slowly.

Western Spruce Budworm--This is the most damaging and widespread of the several insects that defoliate western inland conifers. True firs and Douglas-fir are the preferred hosts for western spruce budworm. Losses from western spruce budworm are steadily and sometimes dramatically rising in response to the increasing acreage of susceptible fir forests.

Douglas-fir Tussock Moth--Outbreaks of this insect occur less frequently and persist shorter than western spruce budworm, but damage in defoliated stands can be more severe. Western inland firs are the preferred hosts. Outbreaks appear to be on the decline.

Bark Beetles--The major bark beetles of western inland conifers include mountain pine beetle, western pine beetle, Douglas-fir bark beetle, spruce beetle, and fir engraver. Together, these and less important bark beetles kill tremendous volumes of trees. Most bark beetle outbreaks develop in stands that have been damaged by storms or fires, or are under stress from factors such as defoliators, overstocking, drought, and root diseases. Losses from bark beetles are slowly declining, as hundreds of thousands of acres of preferred-host types have been destroyed, but very large outbreaks still occur.

Silvicultural Practices

Vast areas of western inland conifers have received treatments for pests, particularly dwarf mistletoes, white pine blister rust, western spruce budworm, tussock moth, and bark beetles. Defoliators, such as western spruce budworm, have been sprayed with several insecticides. Most of the other pests have been treated using cultural methods, with large areas having had some harvesting or other silvicultural treatment. These activities have had a significant effect on pest damage.

In general, stands that are not managed experience more frequent and damaging pest attacks than those treated under any of the five major silvicultural systems.

Single Tree Selection--This silvicultural system poses the greatest risk of continued depredations of western inland conifer stands from the major pests. The potential for losses from stem decays is high because operations conducted during single tree selection typically result in more wounds that serve as infection courts for decay causing fungi. Single tree selection also favors shade-tolerant species that generally suffer the greatest losses from decays. Losses from stem decays can be reduced by taking actions to minimize tree wounding and to remove decayed and scarred trees. Root diseases are most serious in stands managed under single tree selection, primarily because this approach has the greatest potential of leaving infected, but nonsymptomatic, root-diseased trees. Tolerant and semitolerant tree species that are favored in the single tree selection process are also those most susceptible to root diseases. Multiple entries provide a continuing supply of fresh stumps for some for root disease fungi to colonize and spread outward to infect adjacent trees. Dwarf mistletoes are also most likely to be perpetuated by single tree selection because lightly infected trees are likely to be overlooked and left. The mistletoes may flourish

because small openings caused by single tree removals provide sufficient sunlight for mistletoes to produce vigorous aerial shoots and seeds. Single tree selection is also likely to result in multiple-canopy structures that facilitate mistletoe spread and intensify damage. Western spruce budworm and Douglas-fir tussock moth are more likely to be problem pests in the multicanopy stands, with understories of firs resulting in stands managed by single tree selection.

Single tree selection can lower the risk of damage from white pine blister rust, hard pine rusts, and bark beetles and provides opportunities to quickly remove individual pest affected or highly susceptible trees that could serve as foci for outbreaks that could threaten adjacent trees and stands.

Group Selection--This silvicultural system poses many of the same risks for perpetuating major pest problems as did single tree selection. However, the risk is lowered as the size of groups of trees removed increases. Opportunities for treatment of several of the pests improve with the size of openings created. For example, removal of large groups of trees presents lower risk of wounding trees, and thus contributes to less stem decay than with removal of small groups. Similarly, group selection presents opportunities to remove all trees with root diseases and dwarf mistletoes from infection centers and all bark beetle trees from infested spots, especially if the groups can be made large. Group selection presents a better opportunity to plant less susceptible or immune species than single tree selection.

Care needs to be taken in prescribing group selection in stands infested with dwarf mistleoe. If the openings created are small and reforest with susceptible species, the trees in the openings will quickly become infected and will suffer heavy losses. Openings should be large enough to remove all infected trees, otherwise, they should be reforested with immune species.

Group selection also has high potential for increasing the risk from western spruce budworm and Douglas-fir tussock moth by creating multiple-canopy stands and encouraging regeneration of tolerant and semitolerant tree species preferred by these insects. On the other hand, the risk from these insects can be reduced if the openings are large enough to reforest with nonsusceptible species.

Shelterwood and Seed Tree--These two silvicultural systems pose significantly lower risks of perpetuating pest damage than selection systems. Removal of a greater portion of the trees means there is reduced likelihood of leaving pest-infested or highly susceptible trees. Detection and treatment of root diseases are improved because some of the root diseases will produce symptoms of stain and decay that can be seen on freshly cut stump surface even though these trees may not show crown symptoms. This allows more precise delineation of infection centers than is possible with selection systems. Shelterwood and seed tree systems also provide more opportunities to reforest sites with tree species immune, or with low susceptibility, to pests.

The greatest risks associated with shelterwood and seed tree systems are from mechanical injury to understories that may occur during final overstory removal and from dwarf mistletoes spreading from overstory trees. Overstories should be removed as soon as seedlings become established to prevent excessive logging damage to developing reproduction. Shelterwood and seed trees should be carefully selected to be free from dwarf mistletoe infections and should be windfirm to avoid bark beetle buildups in trees that might easily be windthrown. If trees infested with dwarf mistletoe are left to remain, they should be removed before understory trees reach 0.9 m (3 ft) tall.

Clearcutting--Clearcutting presents the lowest risk of perpetuating insect and disease problems. Complete tree removal provides an opportunity to remove all pest-affected and highly susceptible trees. It also offers the best prospects for detecting and successfully treating root diseases, either by reforesting with less susceptible tree species or by stump removal. Similarly, it presents the best chances for controlling dwarf mistletoes, because all infected trees can be included within the cut boundaries and the site can be reforested with alternative species. The risk from western spruce budworm and tussock moth can be minimized by clearcutting because less susceptible tree species can be replanted, and the resulting single-story stands typically suffer less damage than multiple-canopy stands that often develop by other silvicultural approaches.

Other Stand Management Practices--Extensive areas of western inland conifers are precommercially thinned. Such thinning can be effective in reducing susceptibility to all the major pests. Thinning provides

an opportunity to remove scarred trees and species with high stem-decay potential and to discriminate against trees with dwarf mistletoes, rust infections, and insect-caused damage. Unless precommercial thinning is done very carelessly, it will result in reduced pest susceptibility.

Prescribed burning has become a common management tool in western inland conifer forests. If done carelessly, so trees are burned, stem decays and bark beetles will increase. Most burning is carefully executed and can result in reduced pest susceptibility, particularly to root diseases, western spruce budworm, and Douglas-fir tussock moth. Prescribed burning can be effective in preventing encroachment of tolerant and semitolerant tree species into pine sites. These tolerant tree species are subject to more damage from stem decays, root diseases, and defoliators than seral tree species.

Pruning is not a common silvicultural practice, however, it does have good potential for reducing susceptibility to some pests, particularly white pine blister rust, hard pine rusts, dwarf mistletoes, and stem decays. It may be particularly useful in high-use or high-value areas.

Northeastern Conifers

The northeastern conifer forests are not really a specific entity but a wide-ranging mixture of forest types. These types vary from the extensive spruce-fir forests of northern New England and the Lake States to scattered pine stands interspersed with hardwood stands, to mixed conifer-hardwood stands. Ranging from Maine to Minnesota, to Tennessee to Georgia, it includes the following types and species: Red pine (*Pinus resinosa*), jack pine (*P. banksiana*), black spruce (*Picea mariana*), tamarack (*Larix laricina*), northern white-cedar (*Thuja occidentalis*), spruce-fir (balsam fir (*Abies balsamea*)), red spruce (*P. rubens*), and white spruce (*P. glauca*)), eastern white pine (*Pinus strobus*), eastern hemlock (*Tsuga canadensis*), and pitch pine (*Pinus rigida*). By far, the largest acreages occur in the boreal forest areas of Minnesota, Wisconsin, and Michigan; and in Vermont, New Hampshire, Maine, and northern New York,. A number of insect and disease organisms infest these stands, but most of them have relatively minor local impacts and are specific in the species they attack. The major pest organisms resulting in significant impacts are listed in table 4. Brief descriptions of these pests and their damage follow.

Table 4--*Common and scientific names of major insect and disease pests affecting northeastern conifer forests*

Stem decays	Various fungi
Root diseases:	
Shoestring root rot	*Armillaria* spp.
Annosus root rot	*Heterobasidion annosum*
Scleroderris canker	*Gremmeniella abietina*
Eastern dwarf mistletoe	*Arceuthobium pusillum*
White pine blister rust	*Cronartium ribicola*
Insects:	
White pine weevil	*Pissodes strobi*
Eastern spruce budworm	*Choristoneura fumiferana*
Jack pine budworm	*C. pinus pinus*

Major Pests

Stem Decays--Many different fungi contribute to stem decays of northeastern conifers, especially in the spruce-fir type and to a lesser degree, in the other species. Volume losses are quite large, especially in older mature and overmature stands.

Root Diseases--The two most important root diseases of Northeastern conifers are shoestring root rot and annosus root rot. Most species in the northeast are affected. Shoestring root rot is a problem when conifers are planted on hardwood sites following clearcutting. Annosus root rot is a problem in thinned pine stands, especially on well-drained, sandy soils.

Scleroderris Canker--A serious disease of conifers; hard pines (red, jack, and Scots) are most susceptible, while white pine and spruces are resistant, but may be attacked, and balsam fir is immune. The fungus attacks the bud and progresses down the shoot, killing the needles. Branches and main stems up to 7.6 cm (3 in) in diameter develop cankers and may be girdled. The tree is usually killed by the loss of foliage. Asexual spores are spread by rain, and sexual spores by wind. The American strain is primarily a problem on planted and natural seedlings. An aggressive "European" strain in New York and Vermont is especially damaging to large trees in red pine plantations and is increasing its territory.

Eastern Dwarf mistletoe--Dwarf mistletoe is a native parasitic plant found primarily on black spruce and occasionally on red spruce, white spruce, and tamarack. The organism causes branch swelling and masses of twigs, called witchesbrooms, on the host. The mistletoe receives its energy from the tree and several infections on the tree can reduce its vigor enough to kill it.

White Pine Blister Rust--White pine is the single most important coniferous species of the northeast. It grows in pure, natural stands, in mixed conifer stands, in mixed hardwood-conifer stands, and in plantations. White pine blister rust is a disease that begins in the needles, spreads into the branches and stems, and eventually kills the tree via trunk infections. The disease has eliminated white pine from some portions of its range and restricts planting on certain sites within the range.

White Pine Weevil--The white pine weevil prefers eastern white pine and jack pine but can also attack Norway spruce, Scots pine, pitch pine, and red pine. Adults and larvae feed on the previous year's leader and kill all of the branches above the feeding site. One or more lateral shoots may replace the leader, resulting in a crooked or forked stem and small, bushy trees, severely reducing the volume and quality of the stem. Open-grown plantations of white and jack pine are highly susceptible, especially in the northeastern and central portions of white pine's range.

Eastern Spruce Budworm--The spruce budworm prefers to feed on balsam fir, but white, red, and black spruce are suitable hosts and occasional heavy feeding occurs on hemlock; lesser feeding occurs on pines and larches. Defoliation of needles and mining of buds by the budworm has impacted millions of hectares (acres) of spruce-fir forest in the Northeast, resulting in mortality and growth loss on a large scale. Natural outbreaks occur in mature and overmature stands, especially those stands containing large numbers of balsam fir.

Jack Pine Budworm--The jack pine budworm is closely related to the spruce budworm. It prefers to feed on jack pine and will also feed on small red, Scots, and white pine trees in the understory. Defoliation of needles and mining of buds by the budworm results in topkilled and stagheaded jack pine trees, but only rarely do larger trees die. Mortality can be quite heavy in younger understory pine trees (poles, saplings, and seedlings) that are defoliated beneath a jack pine overstory. The jack pine budworm is currently the most serious conifer insect pest in the Lake States.

Silvicultural Practices

These eight major pests interact with the management of northeastern conifers in many ways. In the following discussions of silvicultural systems, only positive and negative interactions of pests, their host forest type, and silvicultural treatments are mentioned. Neutral or unknown effects are not discussed.

Single Tree Selection--Single tree selection is generally used in only two of the northeastern conifers--the spruce-fir type and eastern hemlock. Since single tree selection carries large trees at all times, it has the potential to increase the significance of stem decays in those stands for all types of northeastern conifers if logging damage is not minimized. The periodic cuttings required will also

increase the potential for damage due to root diseases, especially annosus root rot. The regeneration of new seedlings under the older trees provides an ideal situation for the spread of eastern dwarf mistletoe, unless all infested trees are removed and destroyed in the selection cutting. In the spruce-fir type, single tree selection cutting increases spruce at the expense of balsam fir, reducing the susceptibility of the stand to spruce budworm. However, the continual presence of large susceptible trees under single tree selection will offset some of the reduction in susceptibility due to changing the species composition.

Group Selection--This system has the same advantages and disadvantages as single tree selection, but it may offer a few additional advantages. It can be used with white and red pine, while single tree selection cannot. If eastern dwarf mistletoe infections are patchy, a group selection cut could effectively remove all of the infested trees. Group selection could also isolate a discrete root disease pocket and prevent it from spreading. Balsam fir may be more plentiful in group selection cuts resulting in higher susceptibility to spruce budworm, but large trees are not present in the groups reducing susceptibility.

Shelterwood--The shelterwood system has great potential for reducing the impacts of several damaging agents. The system can be used with almost all of the various northeastern conifers. Even-aged systems, including shelterwoods, can reduce losses to stem decays by shortening rotations so large mature and overmature trees are not present. Annosus root rot can be prevented in these stands by applying *Phlebia gigantea*, a competing fungus, to the stumps, or by treating freshly cut stumps with borax. Shelterwood cuts can be used to reduce Eastern dwarf mistletoe provided all infected trees are removed in the shelterwood cut. Otherwise, new seedlings may become infected.

The most important use of shelterwoods for pest reduction has been the reduction of white pine weevil damage on white pine. Regenerating white pine under 30-50 percent shade (or tree cover) will reduce white pine weevil attacks on the leaders and branches of these trees. Once the white pines are 3.7-7.6 m (12-25 ft) tall, the shelterwood can be removed. The weevil will then attack the trees, but the damage will be above the first log of the tree, greatly reducing the economic impact of the weevil. The use of shelterwoods for reduction of white pine weevil damage does not work on jack pine. Shelterwoods are also an excellent choice for reducing spruce budworm impacts. Using shelterwood cuts will increase the amount of spruces and reduce the amount of balsam fir in the stand, decreasing the stand susceptibility. The shelterwoods also favor birds that prey on spruce budworms.

Seed Tree--Seed tree cutting is not used with any regularity in northeastern conifers. While it has many of the same advantages as the other even-aged systems, seed tree cuts do not leave as much shade as shelterwoods and tend to be susceptible to windthrow of the seed trees. Their major use is in mixed conifer--hardwood stands where white pine, in particular, is retained as seed trees to increase its composition in the stand.

Clearcutting--This system is the most common regeneration system used in Northeastern conifers. Depending upon the forest type or species involved, regeneration can be obtained from natural seedlings or artificially by planting nursery stock. As mentioned under shelterwoods, shortening rotations by clearcutting mature and overmature stands will minimize stem decays and will also reduce spruce budworm susceptibility (for example rotations of 45-70 years for spruce-fir). Conifers should not be planted on hardwood stump sites unless the stumps are removed to prevent shoestring root rot from killing the seedlings. The American strain of scleroderris canker can be minimized by using disease-free planting stock and carefully selecting planting sites to avoid high-hazard sites and sites adjacent to infested stands. The European strain can be slowed by clearcutting the entire infested stand and destroying all needle-bearing slash by fire or other means. Clearcutting followed by the destruction of all infested trees is the best treatment for stands heavily infected by Eastern dwarf mistletoe. Fire can also be used to eliminate the infested slash. Clearcutting will increase the damage to white pine by white pine weevil in the northeastern and central portions of its range. Damage to jack pine weevil is also increased by clearcutting, but damage can be minimized by very close spacings when planting or very dense stands of natural regeneration. The dense stands help train the new leaders and prevent the formation of small, bushy trees that never recover. Selection of planting sites to avoid high-hazard sites and planting resistant seedlings can be used to reduce white pine blister rust damage following clearcutting. Clearcutting

spruce-fir stands will increase the amount of balsam fir in them resulting in higher susceptibility to spruce budworm. However, clearcutting can be an effective treatment to eliminate high-risk spruce-fir stands prior to an outbreak. Clearcutting heavily infested stands before maturity can reduce the impact of jack pine budworm.

Other Cultural Practices--Fire or prescribed burning has been mentioned as a valuable tool for destroying disease-infected slash in the previous text. Fire can also reduce the number of some stem decay fruiting bodies in a stand prior to cutting. However, the fire has a risk for wounding trees, providing an entry for stem decays if too hot a fire is used. Logging damage from thinnings also provides wounds for stem decays to invade trees. Pruning can be used to remove branches infested with eastern dwarf mistletoe, scleroderris canker, and white pine blister rust. This treatment prevents the tree from being killed and reduces spread of the diseases to other trees. Intermediate thinnings can be used to remove infected trees (particularly effective in young stands lightly infected with Eastern dwarf mistletoe), favor nonsusceptible species, maintain vigorous stands, shorten rotations, and presalvage trees before they die. Removal of topkilled and stagheaded jack pine trees in thinnings is the only known treatment for reducing impact of jack pine budworm. When doing thinnings in northeastern conifers, logging damage should be minimized to prevent stem decays and stumps should be treated to prevent annosus root rot, as described earlier. Avoiding high-hazard planting sites and selecting resistant genotypes and species will prevent many pest problems from developing. Eradication of *Ribes* spp., alternate hosts of white pine blister rust, can be used to protect some high-value stands in local areas. Diversifying the age classes present in an area will reduce the risk that the entire area will become susceptible to a single pest outbreak.

Eastern Hardwoods

The eastern hardwood forest is a mixture of species and forest types. The largest single type is oak-hickory, covering 46.1 million hectares (114 million acres) in an area bounded by Texas and Florida in the south and Minnesota and Maine in the north. The type is most concentrated in the Appalachian Mountains and Plateaus and the Ozark and Ouachita highlands. Species include numerous oaks and hickories and smaller amounts of many other hardwoods and conifers. An important subtype is 10.5 million hectares (26 million acres) of Appalachian mixed hardwoods that is dominated by yellow-poplar, oaks, ashes, black cherry, maples, and many other species. The next largest type, bottomland hardwoods, occurs along the 21.0 million hectares (52 million acres) of river floodplains, drainages, and swamps in the Eastern United States. Principal species include cottonwood, willows, sycamore, gums, silver maple, several oaks, and many minor species. The oak-pine types cover 14.2 million hectares (35 million acres) and consist of many of the species found in the oak-hickory type along with with pines. The pines include either northern species like pitch, or more southern ones like Virginia, shortleaf, and loblolly. This oak-hickory type occupies a transitional phase between pine and hardwood types. Northern hardwoods, dominated by sugar maple, American beech, yellow birch, and its major subtype, cherry-maple (dominated by black cherry and red maple) cover 8.9 million hectares (22 million acres) in the northern half of the Eastern United States. The remaining hardwood type, aspen-birch, covers 6.1 million hectares (15 million acres); aspens (bigtooth and quaking) dominate in the Lake States, and birches (primarily paper birch with some gray birch) dominate in New England. There are well over 200 species in the eastern hardwood forest and a large number of insects and diseases attack them; most of these pests have minor, local impacts and do not cause large outbreaks. However, certain major pest organisms cause significant impacts; these are listed in table 5.

Brief descriptions of these pests and their damage follow the table.

Table 5--*Common and scientific names of major insect and disease pests affecting eastern hardwood forests*

Gypsy moth	*Lymantria dispar*
Other defoliators	Various insects
Root diseases:	Various fungi
Shoestring root rot	*Armillaria* spp.
Stem decays	Various fungi
Stem borers	Various insects
Beech bark disease complex:	*Nectria coccinea* var. *faginata* *Cryptococcus fagisuga* *Xylococculus betulae*
Vascular and canker diseases:	
Chestnut blight	*Cryphonectria parasitica*
Dutch elm disease	*Ophiostoma* (*Ceratocystis*) *ulmi*
Oak wilt	*Ceratocystis fagacearum*
Sapstreak disease	*Ceratocystis coerulescens*
Declines (diebacks)	Various stress agents and factors and secondary-action organisms
Reproduction insects	Various insects

Major Pests

Gypsy Moth--An introduced pest, the gypsy moth is a defoliator of leaves of more than 500 species, but it especially favors oaks. When larvae are half-grown, they will eat many hardwoods and conifers. Ashes, yellow-poplar, black walnut, and some other species will not be eaten. Defoliation occurs in May and June, usually followed by a new growth of leaves in July. This refoliation process considerably weakens the tree, allowing other insects and disease agents to attack and kill it. Mortality can vary from very light to complete and is increased by drought stress. The nuisance of gypsy moth larvae also creates problems in recreation areas, rural housing areas, and small cities and towns. The gypsy moth is still increasing its range in the United States and eventually will be present over much of the eastern hardwood area.

Other Defoliators--Almost every hardwood species has at least one native defoliator. Some defoliators are specific to one or two species, while others may eat 10 to 20 species; a few eat hundreds of species. Some are spring and some late summer defoliators. Native defoliators periodically reach outbreak proportions in local areas and may cause damage on a scale similar to gypsy moth in these localized situations. Drought stress seems to play an important role in some of these outbreaks. Examples of recent local outbreaks are: cherry scallop shell moth in northwestern Pennsylvania; looper complex in Indiana, Pennsylvania, and West Virginia; forest tent caterpillar and eastern tent caterpillar in New

England; and oak leaftier and leafroller in Pennsylvania.

Root Disease--A number of root diseases cause problems with hardwoods, especially when seedlings are grown in nurseries. The major root disease problem, however, is *Armillaria* spp., the shoestring root rot. *Armillaria* plays an important ecological role in helping to kill and decay roots from trees that cannot compete against healthier, more vigorous trees. It is usually present in all stands. When trees are weakened by stress, such as defoliation, the fungus is able to successfully invade and kill them.

Stem Decays--A number of fungi contribute to stem decays of eastern hardwoods. Some fungi are species-specific, while others attack a wide range of species. Volume losses and degrade are large, especially in older mature and overmature stands.

Stem Borers--A number of insects bore through the wood of hardwood trees, damaging the wood and creating degrade losses worth millions of dollars each year. Some insects, such as carpenterworm and red oak borer, can bore right into the wood, creating holes and tunnels that reduce value. Other insects, such as the twolined chestnut borer, bore in the inner bark and sapwood, first girdling branches and eventually the main stem. They are especially active in trees that have been weakened by drought stress or defoliation, and their activity can kill these trees.

Beech Bark Disease Complex--Beech bark disease is an introduced insect-fungus complex that kills or injures American beech. Two scale insects (see table 5) pierce the bark of beech and then feed. The fungi, *Nectria* species, then infects the bark through these feeding wounds. The tree walls off the damaged area, creating defects and slow growth. Many trees are killed as the bark becomes completely girdled. In 1987, beech bark disease was the second most important disease in New York in terms of volume loss. A few trees show genetic resistance to scale infestation.

Vascular and Canker Diseases--Several vascular and canker diseases have had a major impact on specific hardwoods. Chestnut blight fungus was introduced to the United States in 1904 and has killed nearly all of the mature American chestnut (*Castanea dentata*) trees. The fungus enters through wounds and produces cankers on branches and stems, eventually girdling the tree. However, the roots are not killed, so many trees keep sprouting; most of these sprouts are invaded and eventually killed. The Dutch elm disease fungus also was introduced from Europe. This fungus infects the sapwood of the tree, usually starting in the branches and working down into the stem. Leaves wilt, then branches die, and eventually the entire tree is killed. The fungus is spread by two species of elm bark beetles. Dutch elm disease has almost eliminated mature elm trees from eastern hardwood forests. As with chestnut blight, many small elm trees can be found, but most of these are killed before they mature. Another major disease is oak wilt. This fungus is closely related to the fungus causing Dutch elm disease and works in a similar fashion by invading the the vessels in the wood. Oak wilt is also spread by bark beetles and other insects. Like Dutch elm disease, oak wilt is spread locally through root grafts with adjoining trees. The fungus has killed large numbers of oaks, but it is not as widespread as the previous two diseases. Sapstreak disease of sugar maples is not a significant problem at this time , but it has the potential to become one as management intensifies in the northern hardwood forest type. The fungus, a common sapstaining organism of lumber and wood, becomes lethal when it gains access to the living tree through basal wounds.

Declines (Diebacks)--Dieback and decline are complex diseases triggered by biotic or abiotic stress factors (for example drought, defoliation). Several of the most significant are ash, oak, and maple declines. Beech bark disease, sweetgum blight, and birch dieback are other examples. Terminal branches of trees die back. Trees often become stagheaded. Affected tree mortality is usually the result of stressed trees being attacked by secondary organisms. New research techniques have now provided evidence that one ash decline disease (ash yellows) is caused by a mycoplasma-like organism (MLO).

Reproduction Insects--A number of insects attack seeds and seedlings of hardwoods, especially oaks. *Curculio* weevils can destroy a large percentage of oak acorn crops and can be an important pest in oak, pecan, and walnut seed orchards. Several other species attack both seeds, germinating seedlings, and young seedlings. Some of the most damaging of these insects are *Conotrachelus* weevils, which eat root tissue and kill the new seedlings.

Silvicultural Practices

The above-mentioned pests have both positive and negative interactions with the management of eastern hardwoods. It is interesting to note that many of these destructive pests are introduced from Europe and Asia. Because they are not native pests, they have not been as effectively controlled by the use of management practices. In the following discussions of silvicultural systems, only positive and negative interactions of pests, their host forest type, and silvicultural treatments are mentioned. Neutral or unknown effects are not discussed.

Single Tree Selection--Single tree selection is used only in the northern hardwood type and, to a limited extent, in the cherry-maple and Appalachian mixed hardwoods subtypes. It can be used to reduce the impact of beech bark disease by removing infected trees, large overmature trees, and rough-barked trees in favor of smooth-barked beech trees and resistant beech trees. Individual trees with decline symptoms can be removed using single tree selection. Removing large, overmature trees and logging-damaged trees, and minimizing logging damage will minimize stem decays. Periodic cuttings increase the potential for shoestring root rot damage, if additional stress occurs. Wounds made to residual maple trees afford entry to the sapstreak fungus.

Group Selection--The advantages and disadvantages of single tree selection apply as well to group selection. When used in the oak-pine and oak-hickory types, this system may more quickly help shift species composition toward more tolerant species. This shift will increase diversity and reduce susceptibility of the stand to gypsy moth. Group selection has the advantage over single tree selection for removing larger patches of susceptible beech trees or for removing susceptible trees in an oak wilt pocket. Potential damage from shoestring root rot is lower in group selection than in single tree selection.

Shelterwood--The shelterwood system is the regeneration system of choice for many eastern hardwoods when advanced seedling reproduction is not present. It is used for all types except pure aspen stands. Even-aged systems, including shelterwoods, seed tree, and clearcutting, can reduce losses to stem decays by shortening rotations. Shelterwoods can be used to promote increased species diversity and resistant clones of beech to reduce beech bark disease complex impacts. Declines can be treated by using shelterwoods to regenerate unaffected trees and remove affected trees. *Armillaria* potential is increased temporarily after a shelterwood cut. If stress or defoliation occurs in this time period, significant mortality may occur. Gypsy moth and other defoliators can reduce seed production and success of shelterwood cuts. The increased diversity of species that results from shelterwood harvests will reduce the potential for defoliation impacts in the new stand.

Seed Tree--Seed tree cutting is not used in most of the eastern hardwoods and only rarely in northern hardwoods. Windthrow is a problem with seed trees and can be increased by stem decays or shoestring root rot in the large, mature seed trees.

Clearcutting--This system is the most common regeneration system in eastern hardwoods. Most regeneration is obtained from natural seedlings or sprouts. The only artificial regeneration is in bottomland hardwoods and stripmine reclamation. As mentioned previously, stem decays can be reduced by shortening rotations. Even-aged stands with high concentrations of a single preferred species or of a few preferred species have increased susceptibility to gypsy moth and other defoliators. *Armillaria* is minimized by the long periods between cuttings and by maintaining fast-growing, vigorous trees. Beech bark disease in stands can be reduced by treating diseased trees and sprouts with herbicides and then clearcutting to encouraging other species. Stands with declines can be clearcut to regenerate new stands.

Other Cultural Practices--Fire or prescribed burning has shown potential for reducing populations of reproduction insects that live in the litter. It can also reduce the number of stem decay fruiting bodies in a stand prior to cutting. However, if too hot a fire is used, it can wound trees and encourage stem decays. Pruning can increase stem decays if done on branches larger than 2 inches. It also may provide an entry for oak wilt if done during the growing season and can increase the level of that disease. Site preparation (removing infested stumps and roots) can reduce shoestring root rot and oak wilt, but is an expensive treatment. Intermediate thinnings and timber stand improvement cuts can be used to remove infected trees, favor nonsusceptible species, maintain vigorous stands, provide shorter rotations, presalvage trees before they die, and salvage dead trees. It is a positive treatment for most pests listed in table 5,

especially stem borers. Thinnings have the potential for a negative interaction with shoestring root rot. Shoestring fungus levels can increase shortly after cutting, resulting in mortality if the stand is stressed or defoliated. Logging damage to residual trees during thinnings should be minimized to prevent an increase in stem decays and in sapstreak disease. Also, timber stand improvement (TSI) operations that create stump "wounds" when members of sugar maple sprout clumps are removed can create infection entry points for sapstreak disease. Diversifying the age classes and species compositions present in an area will reduce the risk that the entire area will become susceptible to a single pest outbreak. Managing for and matching the proper species to the site will encourage vigorous, pest-free stands and minimize stress that can trigger pest problems.

Summary

The most effective approach for reducing pest-caused damage to our Nation's forests is to focus on low pest populations and to apply treatments that will reduce the frequency of outbreak occurrence and minimize severity of outbreaks. Preventive silvicultural treatment offers a practical and long-lasting means for achieving this goal. High-hazard stands can be manipulated to reduce risk, high-risk individual trees can be removed, and low-risk stands can be tended to maintain vigor and rapid growth. Managers are encouraged to give thorough consideration of the array and potential impacts of pests as land management plans are developed, and to implement preventive treatments when these strategies are compatible with other management goals.

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Glossary

Definitions contained in this glossary are based on those that appear in the 1971 edition of *Terminology of Forest Science, Technology, Practice and Products*, published by the Society of American Foresters and prepared in conjunction with the Joint Food and Agriculture Organization/International Union of Forestry Research Organizations Committee on Forestry Bibliography and Terminology[1]. In rare instances where definitions were not available from *Terminology of Forest Science, Technology, Practice and Products*, composites were prepared from other sources.

A silvicultural system is sometimes confused with the regeneration cutting after which it is named. The following excerpt explains why this confusion is so prevalent in the literature, regulations, and legislation concerning silvicultural practices[2].

> "The main--but not the only--treatments making up silvicultural systems, involve the cutting or felling of trees. Cuttings are commonly divided into those that help to reproduce forest stands (reproduction or harvest cuttings) and those that maintain vigor and desired composition and structure of the stands in terms of tree species, ages, and size classes (intermediate cuttings).
>
> Reproduction cuttings have such a great influence on the character and management of the new stand--and the forest as a whole--that silvicultural systems are generally named after them. The major systems used in the United States are clearcutting, seed-tree, shelterwood, single-tree selection, and group selection. Each system includes reproduction cuttings to establish seedings and intermediate treatments to culture the developing stand."

Advance growth--Young trees that have become established naturally before regeneration cuttings are begun or a clearcutting is made.

All-aged--A condition of a forest or stand that contains trees of all, or almost all, age classes.

Area regulation--An indirect method of controlling (and roughly determining) the amount of forest produce to be harvested periodically on the basis of stocked area.

Basal area--The area of the cross-section of a tree inclusive of bark at breast height (1.37 m or 4.5 ft, above the ground) most commonly expressed as m^2/ha or ft^2/acre. For a stand, basal area is computed from all living trees.

Biomass--The total quantity, at a given time, of living organisms of one or more species usually expressed in weight per unit area.

Cleaning--Elimination or suppression of competing vegetation from stands not past the sapling stage (5-10 cm or 2-4 in) in diameter as measured 1.37 m or 4.5 ft, above the ground); specifically, removal of (a) weeds, climbers, or sod-forming grasses, as in plantations or (b) trees of similar age or of less desirable species or form than the crop trees which they are, or may soon be, overtopping.

Clearcutting--The cutting method that describes the silvicultural system in which the old crop is cleared over a considerable area at one time. Regeneration then occurs from (a) natural seeding from adjacent stands, (b) seed contained in the slash or logging debris, (c) advance growth, or (d) planting or direct seeding. An even-aged forest usually results.

[1]Society of American Foresters. 1971. Terminology of Forest Science, Technology, Practice and Products. Washington, DC. 349 p.

[2]Society of American Foresters. 1981. Choices in Silviculture for American Forests. Washington, DC. 80 p.

Climax forest--A plant community that represents for its locality and its environment the culminating stage of a natural succession. When the culminating stage is influenced by topography it is termed a topographic climax, and when it is maintained by regular fires it is termed a fire climax.

Co-dominant--A tree with its crown in the upper forest canopy but less free than the dominant trees and freer and taller than the intermediates and suppressed trees. A crown class.

Composition--The representation of tree species in a forest stand, expressed quantitatively as percent by volume or basal area of each species, or as percent by number only in seedling stands.

Coppice--A regeneration method in which standing trees are cut and subsequent crops originate mainly from adventitious or dormant buds on living stumps but also as suckers from roots and rhizomes.

Crop--The major woody growth on a forested area.

Crop tree--A tree that forms, or is selected to form, a component of the final crop--specifically, one selected to be carried through to maturity. Also known as a final crop tree or growing stock tree.

Crown class--Any class into which trees of a stand may be divided based on both their crown development and crown position relative to crowns of adjacent trees. Commonly used crown classes are dominant, co-dominant, intermediate, and suppressed.

Culmination of mean annual increment--For a tree or stand of trees, the age at which the average annual increment is greatest. It coincides precisely with the age at which the current annual increment just equals the mean annual increment of the stand and thereby defines the rotation of a fully stocked stand that yields the maximum volume growth.

Cutting method--Describes cuttings used either to help reproduce forest stands (reproduction or harvest cuttings) or to maintain their vigor and desired composition and structure in terms of tree species, ages, and size classes (intermediate cuttings).

Dominant--A tree with its largely free-growing crown in the uppermost layers of the forest canopy. A crown class.

Epicormic--A type of branch or shoot arising from an adventitious or dormant bud on a stem or branch of a woody plant. Also called an epicormic branch, epicormic shoot, or water sprout.

Even-aged management--The application of a combination of actions that results in the creation of stands in which trees of essentially the same age grow together. The difference in age between trees forming the main canopy level of a stand usually does not exceed 20 percent of the age of the stand at maturity. Regeneration in a particular stand is obtained during a short period at or near the time that a stand has reached the desired age or size for regeneration and is harvested. Cutting methods producing even-aged stands are clearcut, shelterwood, and seed tree.

Even aged--The condition of a forest or stand composed of trees having no, or relatively small, differences in age, although differences of as much as 30 percent are admissible in rotations greater than 100 years of age.

Fire climax--(See **climax forest.**)

Group selection--The cutting method that describes the silvicultural system in which trees are removed periodically in small groups, resulting in openings that do not exceed an acre or two in size. This leads to the formation of an uneven-aged stand in the form of a mosaic of age-class groups in the same forest.

Growing stock--All the trees growing in a forest or in a specified part of it, generally expressed in terms of number or volume.

Habitat type--The aggregate of all areas that support or can support the same primary vegetation at climax.

Habitat type series--All plant associations having the same potential dominant plant species at climax. Under forested conditions, trees are the dominant vegetation.

Harvest cutting--The felling of the final crop of trees either in a single cutting or in a series of regeneration cuttings. Generally, the removal of financially or physically mature trees, in contrast to cuttings that remove immature trees. Also referred to as main felling and major harvest.

Improvement cutting--The elimination or suppression of less valuable trees in favor of more valuable trees, typically in a mixed, uneven-aged forest.

Individual (single) tree selection--The cutting method that describes the silvicultural system in which trees are removed individually, here and there, each year over an entire forest or stand. The resultant stand usually regenerates naturally and becomes all aged.

Intermediate--A tree of the middle canopy dominated by others in the dominant and co-dominant crown classes. A crown class.

Intermediate cutting--Any removal of trees from a stand between the time of its formation or establishment and the harvest cut. Generally taken to include cleaning, thinning, liberation and improvement cuttings, increment felling, and sometimes even salvage and sanitation cuttings.

Intolerance--Trees unable to survive or grow satisfactorily under specific conditions, most commonly used with respect to their sensitivity to shade but also to conditions such as wind, drought, salt, and flooding.

Mean annual increment--The total increment of trees in a stand up to a given age divided by that age, usually expressed in annual cubic meters of growth per hectare (cubic feet of growth per acre.)

Nurse crop--A crop of trees, shrubs, or other plants naturally occurring or artificially introduced to foster another, and generally more important, crop during its youth by protecting it from frost, insolation, or wind.

Overstory--The trees in a forest of more than one story that form the upper or uppermost canopy layer.

Pioneer--A plant capable of invading bare sites (that is, a newly exposed soil surface) and persisting there until supplanted by successor species. A species planted to prepare a site for such successor species, and therefore a nurse crop.

Preparatory cutting--The removal of trees near the end of a rotation, which permanently opens the canopy and enables the crowns of seed bearers to enlarge and to improve conditions for seed production and natural regeneration. Typically done in the shelterwood system.

Progressive clear-strip cutting--A shelterwood system with clearcutting in strips (usually not wider than the height of adjoining trees) generally progressing against the prevailing wind.

Quadrat--A small, clearly demarcated sample area of known size (usually a square decimeter, a square meter, or a milacre (4.05 m^2, or 43.56 ft^2) on which ecological observations are made.

Regeneration--The renewal of a tree crop by natural or artificial means. Also the young crop itself, commonly referred to as reproduction.

Regeneration cutting--Any removal of trees intended to assist regeneration already present or to make regeneration possible.

Release--Freeing a tree or group of trees from competition by cutting or otherwise eliminating growth that is overtopping or closely surrounding them.

Salvage cutting--The exploitation of trees that are dead, dying, or deteriorating (for instance, because they are overmature or have been materially damaged by fire, wind, insects, fungi, or other injurious agencies) before their timber becomes worthless.

Sanitation cutting--The removal of dead, damaged, or susceptible trees done primarily to prevent the spread of pests or pathogens and so promote forest hygiene.

Scarification--Loosening of the topsoil of open areas, or breaking up the forest floor, in preparation for regenerating by direct seeding or natural seedfall.

Seed cutting--Removal of trees in a mature stand to effect permanent openings in the canopy (if not done in a preparatory cutting) and thereby provide conditions for securing regeneration from the seed of trees retained for this purpose. Also the first of the shelterwood cuttings.

Seed Tree--The cutting method that describes the silvicultural system in which the dominant feature is the removal of all trees in one cut except for a small number of seed bearers left singly or in small groups, usually 20-25/ha (8-10/acre). The seed trees generally

are harvested when regeneration is established. An even-aged stand results.

Selection--(See **group selection** and **individual (single) tree selection.**)

Serotinous--A term applied to plant species or individuals that flower or fruit late in the season and to fruit or cones that remain on the tree without opening for 1 or more years (as the serotinous cones of jack pine, lodgepole pine, and the Ocala variety of sand pine).

Shelterwood--The cutting method that describes the silvicultural system in which, in order to provide a source of seed and/or protection for regeneration, the old crop (the shelterwood) is removed in two or more successive shelterwood cuttings. The first cutting is ordinarily the seed cutting, though it may be preceded by a preparatory cutting, and the last is the final cutting. Any intervening cutting is termed removal cutting. An even-aged stand results.

Silvicultural system--A process whereby forests are tended, harvested, and replaced, resulting in a forest of distinctive form. Systems are classified according to the method of carrying out the fellings that remove the mature crop with a view to regeneration and according to the type of forest thereby produced.

Single tree selection--(See **individual tree selection.**)

Site--An area considered in terms of its environment as determined by the type and quality of the vegetation it can carry.

Site class--A measure of the relative productive capacity of a site based upon the volume or height (dominant, co-dominant, or mean) or the maximum mean annual increment of a stand that is attained or attainable at a given age.

Site index--A measure of site class based upon height of the dominant trees in a stand at an arbitrarily chosen age, most commonly at 50 years in the East and 100 years in the West.

Stand--A community of naturally of artificially established trees of any age sufficiently uniform in composition, constitution, age, spatial arrangement, or condition to be distinguishable from adjacent communities, thereby forming a silvicultural or management entity.

Stand density--A measure of the degree of crowding of trees within stocked areas, commonly expressed by various growing-space ratios such as crown length to tree height, crown diameter to diameter at breast height (1.37 m or 4.5 ft, above the ground), or crown diameter to tree height, or of stem (triangular) spacing to tree height.

Stocking--A measure of the proportion of the area in a stand actually occupied by trees expressed in terms of stocked quadrats or percent of canopy closure (as distinct from their stand density).

Structure--Of a forest, crop, or stand, the distribution and representation of age and/or size (particularly diameter) classes, and of crown and other tree classes.

Succession--The gradual supplanting of one community of plants by another.

Suppressed--One of the four main crown classes. Very slowly growing trees with crowns in the lower layer of the canopy and leading shoots not free. Suppressed trees are subordinate to dominant, co-dominant, and intermediates in the crown canopy.

Thinning--A felling made in an immature stand primarily to maintain or accelerate diameter increment and also to improve the average form of the remaining trees without permanently breaking the canopy. An intermediate cutting.

Thinning from above--A thinning that favors the most promising (not necessarily the dominant) stems, with due regard to even distribution over the stand, by removing those trees that interfere with them.

Thinning from below--A thinning that favors the dominants or selected dominants more or less evenly distributed over the stand by removing a varying proportion of the other trees.

Topographic climax--(See **climax forest.**)

Understory--Trees and woody species growing under an overstory.

Uneven-aged management--The application of a combination of actions needed to simultaneously

maintain continuous high-forest cover, recurring regeneration of desirable species, and the orderly growth and development of trees through a range of diameter or age classes. Cutting methods that develop and maintain uneven-aged stands are single tree selection and group selection.

Uneven aged--The condition of a forest, crop, or stand composed of intermingling trees that differ markedly in age. In practice, a minimum age difference of 25 percent of the length of the rotation usually is used.

Volume regulation--A direct method of controlling and determining the amount of timber to be periodically cut by calculations based upon growing stock volume and increment, disregarding area.

Yield--The amount of forest produce that may be harvested periodically from a specified area over a stated period in accordance with the objectives of management.

English to Metric Conversion Factors:

English Unit	x	Conversion Factor	=	Metric Unit
inch	(in)	25.4000	millimeter	(mm)
		2.5400	centimeter	(cm)
foot	(ft)	0.3048	meter	(m)
yard	(yd)	0.9144	meter	(m)
mile	(mi)	1.6093	kilogram	(km)
ounce (avdp)	(oz)	28.3495	gram	(g)
pound (avdp)	(lb)	453.5924	gram	(g)
		0.4536	kilogram	(kg)
ton	(ton)	0.9072	tonne	(t)
ounce (fluid)	(oz)	0.0296	liter	(l)
pint	(pt)	0.4732	liter	(l)
quart	(qt)	0.9464	liter	(l)
gallon	(gal)	3.7854	liter	(l)
square inch	(in^2)	6.4516	square centimeter	(cm^2)
square foot	(ft^2)	929.0341	square centimeter	(cm^2)
		0.0929	square meter	(m^2)
square yard	(yd^2)	0.8361	square meter	(m^2)
acre	(acre)	0.4047	hectare	(ha)
cubic inch	(in^3)	16.3871	cubic centimeter	(cm^3)
cubic foot	(ft^3)	0.0283	cubic meter (stere)	(m^3)
square feet per acre	(ft^2/acre)	0.2296	square meters per hectare	(m^2/ha)
board feet per acre	(fbm/acre)	0.0140	cubic meters per hectare	(m^3/ha)
cord per acre (cord=90 ft^3)	(cord/acre)	6.2975	cubic meters per hectare	(m^3/ha)
cubic feet per acre	(ft^3/acre)	0.0700	cubic meters per hectare	(m^3/ha)
pound per square inch	(lb/in^2)	70.3067	grams per square centimeter	(g/cm^2)
pound per cubic foot	(lb/ft^2)	4.8824	kilograms per square meter	(kg/m^2)
pound per cubic foot	(lb/ft^3)	16.0185	kilograms per cubic meter	(kg/m^3)
pound per cubic yard	(lb/yd^3)	3.9543	kilograms per cubic meter	(kg/m^3)
pound per acre	(lb/acre)	1.1208	kilograms per hectare	(kg/ha)

Index of Authors

Appendix

Trees

Scientific Name	Common Name
Abies concolor var. *concolor* [Gord. and Glend.] Lindl. ex Hildebr.	White Fir
Abies grandis [Dougl. ex D. Don] Lindl.	Grand Fir
Abies lasiocarpa (Hook.) Nutt.	Subalpine Fir
Abies lasiocarpa var. *arizonica* (Merriam) Lemm.	Corkbark Fir
Betula papyrifera (Marsh)	Paper Birch
Juniperus californica (Carr.)	California Juniper
Juniperus deppeana (Steud.)	Alligator Juniper
Juniperus monosperma (Engelm.)	One Seed Juniper
Juniperus occidentalis (Hook.)	Western Juniper
Juniperus osteosperma (Torr., Little)	Utah Juniper
Juniperus scopulorum (Sarg.)	Rocky Mountain Juniper
Larix lyallii (Parl.)	Subalpine Larch
Larix occidentalis (Nutt.)	Western Larch
Libocedrus decurrens (Torr.)	Incense Cedar
Picea engelmannii (Parry ex Engelm.)	Engelmann Spruce
Picea glauca (Moench) Voss	White Spruce
Picea pungens (Engelm.)	Blue Spruce
Pinus albicaulis (Engelm.)	Whitebark Pine
Pinus aristata (Engelm.)	Bristlecone Pine
Pinus cembroides (Zucc.)	Mexican Pinyon
Pinus contorta (Dougl. ex Loud.)	Lodgepole Pine
Pinus edulis (Engelm.)	Pinyon
Pinus flexilis (James)	Limber Pine
Pinus lambertiana (Dougl.)	Sugar Pine
Pinus monophylla (Torr. and Frem.)	Singleleaf Pinyon
Pinus monticola (Dougl. ex D. Don)	Western White Pine
Pinus ponderosa (Dougl. ex Laws)	Ponderosa Pine
Pinus strobiformis (Engelm.)	Southwestern White Pine
Populus balsamifera (L.)	Balsam Poplar
Populus tremuloides (Michx.)	Aspen
Pseudotsuga menziesii var. *glauca* (Beissn.) Franco	Douglas-fir
Quercus spp.	Oaks
Thuja plicata (Donn ex D. Don)	Western Redcedar

Tsuga heterophylla (Raf.) Sarg.	Western Hemlock
Tsuga mertensiana (Bong.) Carr.	Mountain Hemlock

Animals and Birds

Scientific Name	Common Name
Alces alces [Nelson]	Moose
Cervus species (Linnaeus)	Elk
Dendragus obscurus	Blue Grouse
Lepus americanus (Erxleben)	Hare
Odocoileus spp.	Deer
Peromyscus maniculatus [Wagner]	Deer Mouse
Tamiasciurus hudsonicus (Erxleben)	Red Squirrel
Thomomys spp.	Pocket Gopher
Ursus arctos horribilis (Ord)	Grizzly Bear

Insects

Scientific Name	Common Name
Choristoneura occidentalis (Freeman)	Western Spruce Budworm
Dendroctonus spp.	Bark Beetle
Dendroctonus ponderosae (Hopk.)	Mountain Pine Beetle
Dendroctonus pseudotsugae (Hopk.)	Douglas-fir Beetle
Dendroctonus rufipennis (Kirby)	Spruce Beetle
Ips spp.	Ips Beetle
Orgyia pseudotsugata (McDunnough)	Douglas-fir Tussock Moth

Diseases

Scientific Name	Common Name
Arceuthobium spp.	Dwarf Mistletoes
Armillaria mellea (Vahli Fr.) Kummer	Root Rot
Echinodontium tinctorum (E.&E.) E.& E.	Indian Paint Fungus
Neopeckia coulteri (Pk.) Sacc.	Snow Mold
Phellinus weirii (Murr.) Gilb.	Root Rot

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